

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
28 December 2000 (28.12.2000)

PCT

(10) International Publication Number
WO 00/78119 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/US00/16827

(22) International Filing Date: 19 June 2000 (19.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/139,942 18 June 1999 (18.06.1999) US

(71) Applicant (for all designated States except US): **ADVANCED RESEARCH & TECHNOLOGY INSTITUTE, INC.** [US/US]; Suite 100, 1100 Waterway Boulevard, Indianapolis, IN 46202 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **FIELD, Loren, J.** [US/US]; 741 West 72nd, Indianapolis, IN 46260 (US). **PASUMARTHI, Kishore, Babu, S.** [IN/US]; Apartment 208, 1152 North White River Parkway West Drive, Indianapolis, IN 46222 (US).

(74) Agents: **GANDY, Kenneth, A.** et al.; Woodard, Emhardt, Naughton, Moriarty & McNett, Bank One Center/Tower, Suite 3700, 111 Monument Circle, Indianapolis, IN 46204 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

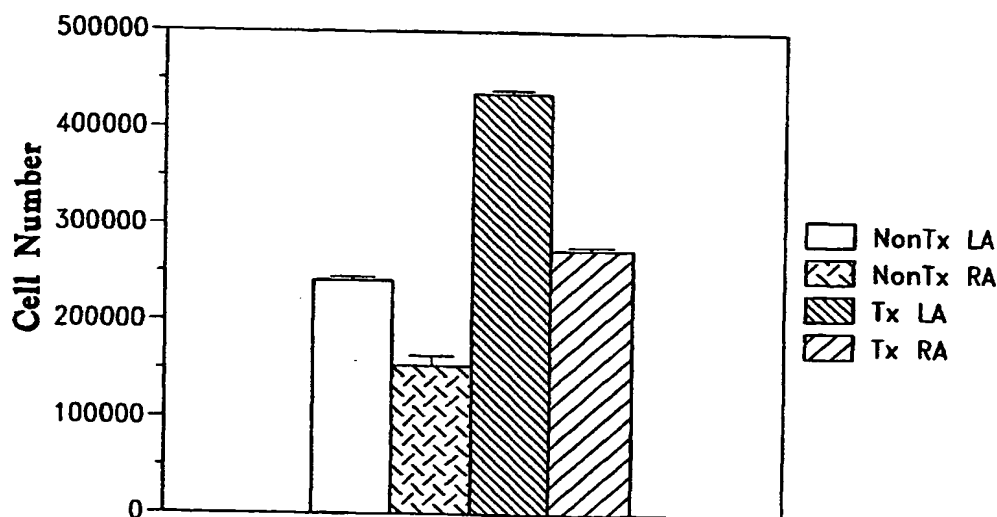
(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— Without international search report and to be republished upon receipt of that report.

[Continued on next page]

(54) Title: **CARDIOMYOCYTES WITH ENHANCED PROLIFERATIVE POTENTIAL, AND METHODS FOR PREPARING AND USING SAME**



(57) Abstract: Described are methods *in vitro* and *in vivo* which involve the use of increased cyclin D2 activity to activate the cell cycle of cardiomyocytes as a baseline measure and/or in response to stimuli. Also described are vectors useful for these purposes, and cardiomyocyte cells exhibiting an activated cell cycle. Transgenic cyclin D2 animal models are also described.

BEST AVAILABLE COPY



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

**CARDIOMYOCYTES WITH ENHANCED PROLIFERATIVE
POTENTIAL, AND METHODS FOR PREPARING AND USING SAME**

5

REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Patent Application Serial No. 60/139,942 filed June 18, 1999, which is hereby incorporated herein by reference in its entirety.

10

BACKGROUND

The present invention relates generally to cardiomyocytes and their use, and in particular aspects to cardiomyocytes containing introduced nucleic acid which encodes a cyclin D2 protein and having increased proliferative capacity, and to methods of making and using such cardiomyocytes.

It is well established that adult mammalian cardiomyocytes exhibit very limited proliferative potential. Studies have shown, for example, that the labeling index for cardiomyocytes in normal adult hearts is less than 0.006% as measured using tritiated thymidine assays with transgenic mice expressing a cardiomyocyte-restricted β -galactosidase reporter to mark cardiomyocyte nuclei. Soonpaa, M.H., and Field, L.J., *Am. J. Physiol.* 266:H1439-1445 (1997). As a result, the mammalian myocardium lacks significant capacity for regenerative growth.

25

Regenerative myocardial growth has enormous therapeutic potential, for example to address many forms of cardiovascular disease characterized by cardiomyocyte death with an ensuing loss of myocardial function. Consequently, efforts have been made to develop strategies to induce cardiomyocyte proliferation. A number of factors have been shown to augment cardiomyocyte DNA synthesis *in vitro* (Oberpriller, J.O., et al., *The Development and Regenerative Potential of Cardiac Muscle*, Hardwood Academic Publishers, Chur, Switzerland/New York (1991)). However, no factor examined to date has proven to induce sustained proliferation of differentiated cardiomyocytes in fetal or adult cultures.

35

The onset of gene transfer techniques has spurred various studies to test the ability of a specific gene product to augment myocardial proliferation *in vitro* or *in vivo*. For example, such studies have been carried out involving the forced
5 expression of *v-myc* (Saule, S. et al., *Proc. Natl. Acad. Sci. USA* 84:7982-7986 (1987); Engelmann, G.L. et al., *J. Mol. Cell. Cardiol.* 25:197-213 (1993)), *c-myc* (Jackson, T. et al., *Mol. Cell. Biol.* 10:3709-3716 (1990); Jackson, T. et al., *Mol. Cell. Biochem.* 104:15-19 (1991)), IGF-1B (Reiss, K. et al., *Proc. Natl. Acad. Sci. USA* 93:8630-8635 (1996)), E1A (Kirshenbaum, L.A., and M.D. Schneider, *J.*
10 *Biol. Chem.* 270:7791-7794 (1995)), and SV40 T antigen (Field, L.J., *Science* 239:1029-1033 (1988); Katz, E., et al., *Am. J. Physiol.* 262:H1867-H1876 (1992)).

Although these research efforts have demonstrated that forced expression of cellular protooncogenes or transforming oncogenes from DNA tumor viruses
15 can promote cardiomyocyte DNA synthesis, and in some cases proliferation, progress on the identification of genes which might be useful to induce regenerative myocardial growth has been difficult and slow.

The mammalian cell cycle has been an area of considerable research
20 interest for many years. This cycle includes a first phase of growth known as the G1 phase, and proceeds then to the S phase, in which DNA replication occurs. The S phase is followed by a second phase of growth known as the G2 phase where cells increase in mass. The cycle terminates in the M phase, which involves nuclear division and cytokinesis. Passage through this cell cycle is
25 regulated at several checkpoints. A highly orchestrated cascade ensures that all requisite activities (genome reduplication, DNA repair, chromosome segregation, etc.) are completed before the initiation of the next step of the cell cycle. The presence of multiple checkpoints can also provide mechanisms for identifying and eliminating of aberrantly growing or genetically compromised cells.

30

Transition through the cell cycle checkpoints is regulated in part by the activity of a family of protein kinases, the cyclin dependent kinases (CDKs), and

their activating partners, the cyclins. In most instances, the initiation of DNA synthesis requires transit through the so-called restriction point, which is at the G1→S boundary of the cell cycle. Transit through this restriction point is to a large extent regulated by CDK4 and the D-type cyclins (*See*, Hunter, T. and J. Pines, *Cell* 79:573-582 (1994); Grana, X. and E.P. Reddy, *Oncogene* 11:211-219 (1995)).

Transgenic experiments have been used to study the forced expression of cyclin D1 in specific cell types. Results have varied dependent upon the cell type.

10 Expression of an MMTV-LTR-cyclin D1 transgene led to constitutive mammary hyperplasia (Wang, T.C. et al, *Nature (Lond.)* 369:669-671 (1994)). In contrast, no lymphocyte hyperplasia was observed in mice carrying an Eμ-cyclin D1 transgene, although mice carrying both Eμ-cyclin D1 and Eμ-*myc* transgenes exhibited accelerated lymphoma formation as compared with mice with the Eμ-*myc* transgene alone (*See*, Bodrug, S.E. et al., *Eur. Mol. Biol. Organ. J.* 13:2124-2130 (1994); and Lovec, H. et al., *Eur. Mol. Biol. Organ. J.* 13:3487-3495 (1994)). Mice carrying a MHC-cyclin D1 transgene exhibit multinucleation and sustained DNA synthesis in adult cardiomyocytes as measured by tritiated thymidine incorporation assays (Soonpaa, M.H. et al., *J. Clin. Invest.* 99:2644-2654 (1997)).

15 20

In view of this background, there remains a need for additional strategies for enhancing the proliferative potential of cells such as cardiomyocytes, and for use of proliferatively-enhanced cells. The present invention addresses these

25 needs.

SUMMARY OF THE INVENTION

A feature of the present invention involves the discovery that increasing cyclin D2 activity in cardiomyocyte cells provides enhanced proliferative potential to the cells. Accordingly, one aspect of the invention concerns a method for enhancing the proliferative potential of a cardiomyocyte cell, comprising increasing the level of cyclin D2 activity in the cardiomyocyte cell. In one form, this may involve introducing nucleic acid into the cardiomyocyte cells, wherein the nucleic acid has a sequence of nucleotides encoding cyclin D2. Such introduction can be carried out with the cell *in vitro* or *in vivo*, and where *in vitro* the modified cell can in one utility thereafter be grafted into a mammal, including a human.

Another aspect of the invention provides a cardiomyocyte cell having introduced nucleic acid encoding cyclin D2, the cardiomyocyte exhibiting increased proliferative potential. The cell may for example have introduced nucleic acid having a coding sequence corresponding to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or of SEQ. I.D. NO. 3 in the Sequence Listing, or having a coding sequence sufficiently similar thereto to encode a protein having cyclin D2 activity. The nucleotide sequence may be operably linked to a promoter, including for example a constitutive promoter, an inducible promoter or a cardiomyocyte-specific promoter.

In another aspect, the invention provides nucleic acid constructs including a sequence of nucleotides encoding cyclin D2 operably linked to a promoter such as an inducible promoter or a cardiomyocyte-specific promoter. The cyclin D2 coding sequence may correspond to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or of SEQ. I.D. NO. 3, or may be a sequence of nucleotides sufficiently similar thereto to encode a protein having cyclin D2 activity.

The present invention also provides a method for increasing the proliferative potential of myocardial cells in a mammal. This method involves

increasing the level of cyclin D2 activity in cardiomyocytes in myocardial tissue of the mammal, so as to result in an increased proliferative potential. For example, cardiomyocytes within myocardial tissue can be genetically transduced with an expression vector incorporating nucleic acid encoding cyclin D2 operably
5 linked to a promoter such as a constitutive, inducible or cardiomyocyte-specific promoter.

The invention herein also concerns a method for grafting cardiomyocytes in a mammal. The method includes grafting cardiomyocytes or cardiomyogenic
10 cells into a mammal, wherein the cardiomyocytes exhibit an increased level of cyclin D2 activity and have increased proliferative potential. The grafted cells may have introduced nucleic acid encoding cyclin D2 operably linked to a promoter such as a constitutive, inducible or cardiomyocyte-specific promoter.

Also provided by the invention are methods for inducing an increase in the proliferative potential of cardiomyocytes in myocardial tissue of a mammal. The methods include providing cardiomyocytes in myocardial tissue of the mammal, wherein the cardiomyocytes are responsive to a pharmacologic agent to increase the proliferative potential of the cardiomyocytes. The agent is administered to the
15 mammal so as to achieve an increase in the proliferative potential of the cardiomyocytes. The inducible cardiomyocytes may for instance be provided as grafted inducible cells within the myocardial tissue, or may result from an *in vivo* genetic transduction of existing cells in the myocardial tissue.
20

In another embodiment, the present invention provides a modified D-type cyclin, wherein the cyclin has been modified to remove one or more (and potentially all) phosphorylation sites present in its native form.
25

The present invention provides cardiomyocyte cells having enhanced proliferative capacity, and methods and materials for making and using such cells.
30 Additional embodiments and features of the invention will be apparent from the descriptions herein.

DESCRIPTION OF THE FIGURES

Figure 1 is a schematic diagram showing a map of the MHC-CYCD2
5 transgene prepared as described in Example 1.

Figure 2 presents the results of a Western blot analysis of cyclin D2
expression in the hearts of control mice (-) and transgenic mice (lines designated
10 10, 9, 5 and 3) carrying the transgene shown in Figure 1, prepared as described in
Example 2..

Figures 3A and 3B are photomicrographs presenting the results of a pulse
chase experiments demonstrating cardiomyocyte DNA synthesis and kariokinesis,
respectively, *in vivo* in MHC-CYCD2 mice in response to a pharmacologic
15 stimulus, as further described in Example 3.

Figure 4 provides a bar graph showing increased cell numbers in the left
and right atria of transgenic MHC-CYCD2 mice as compared to nontransgenics,
generated as described in Example 7.

20

Figure 5 provides a bar graph illustrating that culture of cardiomyocytes
from the left atria of MHC-CYCD2 transgenic mice in the presence of
isoproterenol leads to an increase in the number of cardiomyocyte nuclei in the
culture, as described in Example 8.

25

Figures 6A and 6B provide digital images of transgenic MHC-CYCD2
cardiomyocytes undergoing cytokinesis, obtained as described in Example 9.

Figures 7A and 7B provide photomicrographs illustrating DNA synthesis
30 of cardiomyocytes in transgenic MHC-CYCD2 mice in a cautery injury model
emulating infarction, obtained as described in Example 10.

Figure 8 provides a schematic diagram of a STK-rMHC-Switch-CycD2 virus, as described in Example 11 below.

Figure 9 provides a schematic diagram of a STK-rMHC-CycD2-nLAC
5 virus, as described in Example 12 below.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the purpose of promoting an understanding of the principles of the invention, reference will now be made to certain preferred embodiments thereof and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations, further modifications and applications of the principles of the invention as described herein being contemplated as would normally occur to one skilled in the art to which the invention relates.

As described herein, it has been discovered that increasing the level of cyclin D2 activity can be used to provide to a cell, e.g. a generally non-proliferative cell, such as a mammalian cardiomyocyte, an enhanced proliferative potential. The invention makes available, *inter alia*, novel cells with enhanced proliferative potential, novel methods involving the use of such cells *in vivo* or *in vitro*, novel genetic constructs and methods useful for modifying cells to obtain cells of enhanced proliferative potential, novel cellular grafting methods, and novel animal models having such cells.

Cyclin D2 proteins of mammalian origin, including for example the mouse and human proteins, are known. United States Patent No. 5,869,640, issued February 9, 1999, discloses amino acid and nucleotide sequences for D-type cyclins, including cyclin D2 proteins, as well as characterizing data, and is hereby incorporated herein by reference in its entirety. Cyclin D2 is structurally related to but distinct from the other known D-type cyclins, cyclin D1 and cyclin D3. These D-type cyclins bind to and activate CDK4 and CDK6. This protein complex then phosphorylates members of the retinoblastoma family, thereby releasing E2F family members (which are normally bound to and thereby inhibited by hypophosphorylated RB family members). Released E2F initiates cell cycle progression by promoting the transcription of a variety of gene products needed for DNA synthesis.

Basic structural properties of known native D-type cyclins are presented in Table 1 below:

TABLE 1

5

| <u>Cyclin</u> | <u>Molecular Weight (daltons)</u> | <u># Amino Acids</u> | <u>Phosphorylation Sites (#)</u> |
|---------------|-----------------------------------|----------------------|--|
| D1 | 33,426 | 295 | cAMP Kinase (1) Ca Kinase (1) CKII Kinase (1) GSK3 Kinase (6) |
| D2 | 32,849 | 289 | GSK 3 Kinase (3) |
| D3 | 32,408 | 292 | cAMP Kinase (3) Ca Kinase (3) GSK3 Kinase (4) |

Many prior reports have suggested that these three cyclins are functionally redundant. However, the discoveries herein reveal that significant functional differences exist between cyclin D2 and cyclins D1 and D3. Illustratively, Table 2 below provides a comparison of ventricular and left atrial DNA synthesis measured in hearts of transgenic cyclin D2 mice to that in corresponding transgenic cyclin D1 and D3 mice. In each case, testing was performed generally as described in Example 3 below (HW/BW = heart weight/body weight; Iso = isoproterenol treated). The cautery injury (C.I.) data (emulative of infarct) were obtained using procedures generally as described in Example 10 below.

10

15

TABLE 2

| Mice | HW/BW (%sibs) | Ventricular DNA Synth. (%) | | | Left Atrial DNA Synth. (%) | |
|------------------|------------------|----------------------------|-------------------|-------------------|----------------------------|------------------|
| | | Baseline | Iso(7 days) | C.I. | Baseline | Iso(7 days) |
| Cyclin D1 (n) | 136.9 ± 10.58 | 0.12 (20021) | 0.00 (25060) | 0.015 (139000) | 0.00 (~25000) | 0.00 (~16000) |
| Cyclin D2 (n) | 120.2 ± 4.98 | 0.20 (35029) | 0.12 (32007) | 0.53 (3203) | 0.31 (18311) | 7.28 (22706) |
| Cyclin D3 (n) | 130.9 ± 7.52 | 0.22 (22005) | 0.00 (25425) | 0.01 (~25000) | 0.00 (~25000) | 0.00 (~16000) |
| Control (n) | 100 | 0.0005 (180000) | 0.00 (~200000) | 0.0083 (36000) | 0.00 (18000) | 0.00 (18000) |

5

As can be seen, DNA synthesis did not cease in response to treatment with isoproterenol in the transgenic cyclin D2 mice, whereas it did in the transgenic cyclin D1 and D3 mice. In addition, DNA synthesis in the transgenic cyclin D2 mice increased in response to cautery injury (see ventricular data above) and treatment with isoproterenol (left atrial data). Accordingly, cyclin D2 exhibits functional characteristics distinct from those of cyclins D1 and D3.

A comparison of the amino acid sequence of cyclin D2 to those of D1 and D3 reveals several domains of substantial difference. For example, D2 differs significantly from D1 in domains occurring at about amino acid residues 200-240 and 260-280. D2 differs significantly from D3 in domains occurring at about amino acid residues 210-225 and 250-280. Thus, cyclin D2 differs from both cyclins D1 and D3 in a region spanning about nucleotides 200-280. Functionally, these cyclins differ in their propensity for phosphorylation sites, as illustrated in Table 1. As expected, many of these sites reside within the domains of non-homology identified above.

SEQ. I.D. NO. 1 shows the nucleotide sequence and deduced amino acid sequence for mouse cyclin D2 as utilized in the Examples herein (see also Genbank Accession No. 83749 for the mouse cyclin D2 sequence). SEQ. I.D. NO. 3 shows the nucleotide sequence and deduced amino acid sequence for human cyclin D2. In this regard, the term "nucleotide sequence," as used herein, is intended to refer to a natural or synthetic sequential array of nucleotides and/or nucleosides, and derivatives thereof. The term amino acid sequence is intended to refer to a natural or synthetic sequential array of amino acids and/or derivatives thereof. The terms "encoding" and "coding" refer to the process by which a nucleotide sequence, through the mechanisms of transcription and translation, provides the information to a cell from which a series of amino acids can be assembled into a specific amino acid sequence to produce a polypeptide.

It will be understood that the present invention also encompasses the use of nucleotide sequences and amino acid sequences which differ from the specific cyclin D2 sequences disclosed herein, but which have substantial identity thereto and thereby exhibit characteristic cyclin D2 activity as identified herein. Such sequences will be considered to provide cyclin D2 nucleic acid and cyclin D2 proteins for use in the various aspects of the present invention. For example, nucleic acid sequences encoding variant amino acid sequences are within the scope of the invention. Modifications to a sequence, such as deletions, insertions, or substitutions in the sequence, which produce "silent" changes that do not substantially affect the functional properties of the resulting polypeptide molecule are expressly contemplated by the present invention. For example, it is understood that alterations in a nucleotide sequence which reflect the degeneracy of the genetic code, or which result in the production of a chemically equivalent amino acid at a given site, are contemplated. Thus, a codon for the amino acid alanine, a hydrophobic amino acid, may be substituted by a codon encoding another less hydrophobic residue, such as glycine, or a more hydrophobic residue, such as valine, leucine, or isoleucine. Similarly, changes which result in substitution of one negatively charged residue for another, such as aspartic acid

for glutamic acid, or one positively charged residue for another, such as lysine for arginine, can also be expected to produce a biologically equivalent product.

Also, phosphomimetic mutations such as substitution of serine for aspartic
5 acid in a serine-specific protein kinase consensus sequence can be expected to produce a product mimicking a constitutively phosphorylated Cyclin D2 product.

Nucleotide changes which result in alteration of the N-terminal and C-
terminal portions of the encoded polypeptide molecule would also not generally
10 be expected to alter the activity of the polypeptide. In some cases, it may in fact be desirable to make mutations in the sequence in order to study the effect of alteration on the biological activity of the polypeptide. Each of the proposed modifications is well within the routine skill in the art.

15 In one manner of defining the invention, nucleic acid (e.g. DNA) may be used that has a coding sequence that differs from that set forth in SEQ. I.D. NO. 1 (nucleotides 4-870) or from that set forth in SEQ. I.D. NO. 3 (nucleotides 4-870), wherein the nucleic acid, or at least the coding portion thereof, will bind to nucleic
acid having nucleotides 4-870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3 under
20 stringent conditions, and which nucleic acid encodes a polypeptide having cyclin D2 activity. "Stringent conditions" are sequence dependent and will be different in different circumstances. Generally, stringent conditions are selected to be about 5°C lower than the thermal melting point (T_m) for the specific sequence at a defined ionic strength and pH. The T_m is the temperature (under defined ionic
25 strength and pH) at which 50% of the target sequence hybridizes to a perfectly matched probe. Typically, stringent conditions will be those in which the salt concentration is at least about 0.02 molar at pH 7 and the temperature is at least about 60°C.

30 In one preferred aspect, the encoded polypeptide will retain phosphorylation site characteristics consistent with those of the native cyclin D2 polypeptide, having fewer phosphorylation sites than native cyclin D1 (9 sites)

and D3 (10 sites), and/or lacking cAMP kinase, Ca kinase, and/or CKII kinase phosphorylation sites, and/or containing only GSK3 kinase phosphorylation site(s). Furthermore, cyclin D2 may be modified in accordance with the present invention using site directed mutagenesis to reduce the number of, or eliminate
5 completely, its phosphorylation sites. Additionally, cyclins D1 and D3 may be modified to reduce the number of, or eliminate completely, their phosphorylation sites using site directed mutagenesis, to arrive at D-type cyclins that more closely emulate cyclin D2 in regard to phosphorylation capacity. Such modifications can be achieved, for example, by eliminating phosphorylatable amino acids such as
10 serine and threonine, and replacing them with non-phosphorylatable amino acids, preferably non-charged, non-polar amino acids such as alanine which do not detrimentally impact the conformation of the protein. Cyclins D1 and D3 may also be modified to replace one or more other regions of non-homology with cyclin D2 with corresponding D2 regions, to provide composite D-type cyclins
15 exhibiting functional characteristics similar to those demonstrated by cyclin D2 herein. These and/or other potential modifications to native D-type cyclins to provide modified D-type cyclins having characterizing activities consistent with those demonstrated by cyclin D2 herein (e.g. maintained DNA synthesis in response to insult and/or inducibility) are contemplated as forming a part of the
20 present invention.

In another manner of defining the invention, nucleic acid may be used that encodes a polypeptide that has an amino acid sequence which has at least about 70% identity, more preferably at least about 80% identity, most preferably a least
25 about 90% identity, with the amino acid sequence set forth in SEQ. I.D. NO. 2, or SEQ. I.D. No. 4 or with at least one significant length (i.e. at least 40 amino acid residues) segment thereof, and which polypeptide possesses cyclin D2 activity. The polypeptide may, for example, have an amino acid sequence which has at least about 70% , 80%, or 90% identity with amino acid residues 200-280 of SEQ.
30 I.D. NO. 2 or SEQ. I.D. No. 4, which represent a region in which cyclin D2 differs from cyclins D1 and D3. Percent identity, as used herein, is intended to mean percent identity as determined by comparing sequence information using the

advanced BLAST computer program, version 2.0.8, available from the National Institutes of Health, USA. The BLAST program is based on the alignment method of Karlin and Altschul, *Proc. Natl. Acad. Sci. USA* 87:2264-68 (1990) and as discussed in Altschul, et al., *J. Mol. Biol.* 215:403-10 (1990); Karlin and
5 Altschul, *Proc. Natl. Acad. Sci. USA* 90:5873-7 (1993); and Altschul et al. (1997) *Nucleic Acids Res.* 25:3389-3402. Briefly, the BLAST program defines identity as the number of identical aligned symbols (i.e., nucleotides or amino acids), divided by the total number of symbols in the shorter of the two sequences. The program may be used to determine percent identity over the entire length of the proteins
10 being compared. Preferred default parameters for the BLAST program, blastp, include: (1) description of 500; (2) Expect value of 10; (3) Karlin-Altschul parameter $\lambda = 0.270$; (4) Karlin-Altschul parameter $K = 0.0470$; (5) gap penalties: Existence 11, Extension 1; (6) H value = $4.94e^{-324}$; (6) scores for matched and mismatched amino acids found in the BLOSUM62 matrix as described in
15 Henikoff, S. and Henikoff, J.G., *Proc. Natl. Acad. Sci. USA* 89:10915-10919 (1992); Pearson, W.R., *Prot. Sci.* 4:1145-1160 (1995); and Henikoff, S. and Henikoff, J.G., *Proteins* 17:49-61 (1993). The program also uses an SEG filter to mask-off segments of the query sequence as determined by the SEG program of Wootton and Federhen *Computers and Chemistry* 17:149-163, (1993).

20

In another form, nucleic acid may be used that includes a coding sequence that has at least about 70% identity with the coding portion of the nucleotide sequence set forth in SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3 (nucleotides 4 to 870), or with at least one significant length (i.e. at least 100 nucleotides) segment
25 thereof, and which nucleic acid encodes a polypeptide possessing characteristic cyclin D2 activity as identified herein. The nucleic acid may, for example, have a coding sequence which has at least about 70% at least about 80%, or at least about 90%, identity with nucleotides 601 to 843 (coding for amino acids 200-280) of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3.

30

The nucleotide sequence may be operably linked to a promoter sequence as known in the art to provide recombinant nucleic acid useful in a variety of

applications including, for example, in the provision of vehicles such as vectors for functionally introducing the nucleic acid in to mammalian or other eukaryotic cells. As defined herein, a nucleotide sequence is "operably linked" to another nucleotide sequence (e.g. a regulatory element such as a promoter) when it is placed into a functional relationship with the other nucleotide sequence. For example, if a nucleotide sequence is operably linked to a promoter sequence, this generally means that the nucleotide sequence is contiguous with the promoter and the promoter exhibits the capacity to promote transcription of the gene. A wide variety of promoters are known in the art, including cell-specific promoters, inducible promoters and constitutive promoters. The promoters may be selected so that the desired product produced from the nucleotide sequence template is produced constitutively in the target cells. Alternately, promoters such as inducible promoters may be selected that require activation by activating elements known in the art, so that production of the desired product may be regulated as desired. Still further, promoters may be chosen that promote transcription of the gene in one or more selected cell types, e.g. the so-called cell-specific promoters.

In a preferred aspect of the invention, the cyclin D2 nucleotide sequence is operably linked to a cardiomyocyte cell-specific promoter, for example, providing for constitutive expression of the nucleotide sequence in cardiomyocytes. Illustrative candidates for such promoters include the α -myosin heavy chain (α -MHC) promoter, the β -myosin heavy chain (β -MHC) promoter, the myosin light chain-2V (MLC-2V) promoter, the atrial natriuretic factor (ANF) promoter, and the like. Such constructs enable the expression of the cyclin D2 nucleic acid selectively in cardiomyocyte cells.

Another aspect of the invention provides recombinant nucleic acid that includes a cyclin D2 nucleotide sequence operably linked to an inducible promoter, such that cyclin D2 expression and enhancement of the proliferative capacity of cells incorporating the nucleic acid can be upregulated in response to an inducing agent. Illustrative candidate inducible promoter systems include, for example, the metallothionein (MT) promoter system, wherein the MT promoter is

induced by heavy metals such as copper sulfate; the tetracycline regulatable system, which is a binary system wherein expression is dependent upon the presence or absence of tetracycline; a glucocorticoid responsive promoter, which uses a synthetic sequence derived from the glucocorticoid response element and is
5 inducible *in vivo* by administering dexamethasone (cells having the appropriate receptor); a muristerone-responsive promoter, which uses the gonadotropin-releasing hormone promoter and is inducible with muristerone (cells having the appropriate receptor); and TNF responsive promoters. Additional inducible promoters which may be used, and which are more preferred, include the
10 ecdysone promoter system, which is inducible using an insect hormone (ecdysone) and provides complete ligand-dependent expression in mammals; the β -GAL system, which is a binary system utilizing an *E. coli* lac operon operator and the I gene product in trans, and a gratuitous inducer (IPTG) is used to regulate expression; and, the RU486 inducible system, which uses the CYP3A5 promoter
15 and is inducible by RU486, a well defined pharmaceutical agent. These and other similar inducible promoter systems are known, and their use in the present invention is within the purview of those skilled in the area.

The present invention also concerns vectors which incorporate a cyclin D2
20 nucleotide sequence and which are useful in the genetic transduction of myocardial cells *in vitro* or *in vivo*. A variety of vector systems are suitable for these purposes. These include, for example, viral vectors such as adenovirus vectors as disclosed for example in Franz et al., *Cardiovasc. Res.* 35(3):560-566 (1997); Inesi et al., *Am. J. Physiol.* 274 (3 Pt. 1):C645-653 (1998); Kohout et al.,
25 *Circ. Res.* 78(6):971-977 (1996); Leor et al., *J. Mol. Cell Cardiol.* 28(10):2057-2067 (1996); March et al., *Clin. Cardiol.* 22(1 Suppl. 1):I23-29 (1999); and Rothman et al., *Gene Ther.* 3(10):919-926 (1996). Adeno-Associated Virus (AAV) vectors are also suitable, and are illustratively disclosed in Kaptlitt et al., *Ann. Thorac. Surg.* 62(6):1669-1676 (1996); and Svensson et al., *Circulation*
30 99(2):201-205 (1999). Additional viral vectors which may be used include retroviral vectors (see e.g. Prentice et al., *J. Mol. Cell Cardiol.* 28(1):133-140 (1996); and Petropoulos et al., *J. Virol.* 66(6):3391-3397 (1992)), and Lenti (HIV-

1) viral vectors as disclosed in Rebolledo et al., *Circ. Res.* 83(7):738-742 (1998). A preferred class of expression vectors will incorporate the cyclin D2 nucleic acid operably linked to a cardiomyocyte-specific promoter, such as one of those identified above. Still further, AAV vectors are highly compatible for use in
5 transfection of myocardial cells and tissue, and are preferred from among those identified above.

In accordance with the invention, cardiomyocytes can also be genetically transduced with cyclin D2 nucleic acid *in vitro* or *in vivo* using liposome-based
10 transduction systems. A variety of liposomal transduction systems are known, and have been reported to successfully deliver recombinant expression vectors to cardiomyocytes. Illustrative teachings may be found for example in R.W. Zajdel, et al., *Developmental Dynamics*. 213(4):412-20 (1998); Y. Sawa, et al., *Gene Therapy*. 5(11):1472-80 (1998); Y. Kawahira, et al., *Circulation* 98(19
15 Suppl.):II262-7; discussion II267-8 (1998); G. Yamada, et al., *Cellular & Molecular Biology* 43(8):1165-9 (1997); M. Aoki, et al., *Journal of Molecular & Cellular Cardiology* 29(3):949-59 (1997); Y. Sawa, et al., *Journal of Thoracic & Cardiovascular Surgery* 113(3):512-8; discussion 518-9 (1997); and I. Aleksic, et al., *Thoracic & Cardiovascular Surgeon* 44(2):81-5 (1996). Thus, liposomal
20 recombinant expression vectors including cyclin D2 DNA can also be utilized to transduce cardiomyocytes *in vitro* and *in vivo* for the purposes described herein.

Nucleic acid constructs can be used for example to introduce nucleotide sequences encoding a cyclin D2 protein into cardiomyocyte cells *in vivo* or *in*
25 *vitro*, to achieve a level of intracellular cyclin D2 activity that is increased relative to the native level of the cardiomyocyte cells. Such increased activity can provide an enhanced proliferative capacity to the cells. An enhanced proliferative capacity can be evidenced, for example, by an increase in the level of DNA synthesis and nuclear number (kariokinesis), and/or the exhibition of increased levels of
30 cytokinesis or cell division and consequent increases in cell number. DNA synthesis can be monitored in conventional fashion, for example by tritiated thymidine incorporation analysis. Cytokinesis can also be conventionally detected, e.g. by standard cell counting techniques *in vitro* or *in vivo* or generally

by the observation of increased cell mass or density correlated to increased cell numbers. Alternatively or in addition, purified (e.g. purified recombinant) cyclin D2 protein may be introduced into cells to increase cyclin D2 activity (e.g. by fusogenic liposomes or other macromolecular delivery systems), or the cells can
5 be treated with pharmacologic agents which increase cyclin D2 activity, to provide increased proliferative potential to the cells.

The present invention makes available methods which can be applied *in vitro* or *in vivo* for research, therapeutic, screening or other purposes. Methods for the
10 *in vitro* culture of cardiomyocytes expressing introduced cyclin D2 DNA can be used, for example, in the study and understanding of the cell cycle, in screening for chemical or physical agents which modulate cyclin D2 activity or other aspects of the cell cycle, or in the culture of cardiomyocyte cells for subsequent engraftment into a mammal, including humans.

15
Cardiomyocyte cells to be cultured in accordance with the invention can be derived from a variety of sources. For example, they may be harvested from a mammal for culture and subsequent engraftment into that mammal (autografts) or another mammal of the same species (allografts) or a different species
20 (xenografts). The cardiomyocyte cells may also be derived from the differentiation of stem cells such as embryonic stem cells, or other similar pluripotent cells such as somatic stem cells that differentiate to cardiomyocytes. General methodology for such derivations is disclosed in U.S. Patent Nos. 5,602,301 and 5,733,727 to Field et al. In this regard, when so derived, the
25 genetic modification to incorporate the cyclin D2 nucleic acid may take place at the stem cell level, for instance utilizing one or more vectors to introduce the cyclin D2 nucleic acid operably linked to a cardiomyocyte-specific promoter, and nucleic acid enabling the selection of cardiomyocytes from other cells differentiating from the stem cell and/or at a differentiated level e.g., including a
30 selectable marker gene operably linked to a cardiomyocyte – specific promoter. Nucleic acid enabling selection of transformed from non-transformed stem cells may also be used in such strategies. Such selection of the stem and/or

cardiomyocyte cells may be achieved, illustratively, utilizing a gene conferring resistance to an antibiotic (e.g. neomycin or hygromycin) or other chemical agent operably linked to an appropriate promoter or by using a reporter operably linked to an appropriate promoter allowing for selection of cells by fluorescence activated cells sorting (FACS), for example the known GFP reporter.

Using stem-cell derived cardiomyocytes, the genetic modification to incorporate the cyclin D2 and potentially other nucleic acid may also occur after differentiation of the stem cells. For example, a differentiated cell population enriched in cardiomyocytes, for instance containing 90% or more cardiomyocytes, may be transformed with a vector having cyclin D2 nucleic acid operably linked to a promoter (optionally cardiomyocyte specific), as described above. The same or a different vector may also be used to introduce other functional nucleic acid to the cells, for example providing a reporter gene and/or selectable marker, or providing for the expression of a growth factor and/or another cell cycle regulatory protein.

In one mode of carrying out the invention, left ventricular, right ventricular, left atrial, or right atrial cardiomyocytes, or a mixture of some or all of these, may be genetically modified *in vitro* to incorporate functional cyclin D2 nucleic acid using a suitable vector as disclosed above. Cells to be genetically transduced in such protocols may be obtained for instance from animals at different developmental stages, for example fetal, neonatal and adult stages. Suitable animal sources include mammals such as bovine, porcine, equine, ovine and murine animals. Human cells may be obtained from human donors or from a patient to be treated. The modified cardiomyocytes may thereafter be implanted into a mammal, for example into the left or right atrium or left or right ventricle, to establish a cellular graft in the mammal. Implantation of the cells may be achieved by any suitable means, including for instance by injection or catheterization. In addition to the cyclin D2 nucleic acid, the cells may also be modified *in vitro* to contain other functional nucleic acid sequences which can be expressed to provide other proteins, for example growth factors such as nerve

growth factors, or angiogenic factors such as vascular endothelial growth factor-1 (VEGF-1), or one or more additional cell cycle regulatory proteins or other proteins which act as co-factors with cyclin D2 in increasing cellular proliferative potential.

5

Cardiomyocyte cells for culture, and potential implantation, may also be obtained from the heart of a transgenic animal (especially mammal) expressing introduced cyclin D2 nucleic acid. Using known techniques, transgenic animals which harbor introduced cyclin D2 nucleic acid in essentially all of their cells can be raised, and used either as a source for harvesting culturable cardiomyocyte cells or as animal models for research or screening purposes. For instance, transgenic bovine, porcine, equine, ovine or murine animals may be used as sources for the cardiomyocyte cells or as animal models for study.

15 The present invention also provides for the genetic modification of cardiomyocytes *in vivo* to introduce functional cyclin D2 nucleic acid. An expression vector containing cyclin D2 nucleic acid, for instance one as described above, may be delivered to myocardial tissue of a recipient mammal, to achieve transduction of cardiomyocytes in the tissue. In preferred modes, the cyclin D2
20 nucleic acid in such vector will be operably linked to a cardiomyocyte-specific promoter. The delivery of the vector can be suitably achieved, for instance, by injection, catheterization, or infusion into the blood stream. It will be understood that any mode of delivery which enables the establishment of transduced cardiomyocytes within the myocardial tissue of the recipient mammal is
25 contemplated as being within the present invention. A single delivery of the vector may be used, or multiple deliveries nearly simultaneous or over time may be used, in order to establish a substantial population of transduced cells within the recipient. The transduced cells will then express the cyclin D2 protein, for instance under the control of a constitutive, inducible or cardiomyocyte-specific
30 promoter, and thereby be reactivated to the cell cycle and exhibit an enhanced proliferative potential.

The implantation of cardiomyocytes or cardiomyogenic stem cells (e.g. genetically transduced stem cells as discussed herein) cultured *in vitro* or the delivery of the vector for *in vivo* genetic transduction may be directed or may home to a selected site or sites within the heart of the recipient. Such site or sites
5 may be in the left or right atrium or left or right ventricle of the recipient, or any combination of these. Commonly, the implantation or delivery site or sites will occur in the left or right ventricle of the recipient. The site(s) may, for instance, be one(s) in which there is a need for additional viable cells, for example in a damaged or diseased area of the heart such as in cases of myocardial infarcts and
10 cardiomyopathies. The site(s) may also be targets for the delivery of other proteins such as growth factors, e.g. nerve growth or angiogenic factors, as discussed above, via expression in the grafted or *in vivo* transduced cells.

In another aspect of the invention, it has been discovered that cardiomyocytes
15 having increased cyclin D2 activity can be provided which, in response to contact with a pharmacologic agent, exhibit a substantial increase in proliferative potential. For example, such increases in proliferative potential have been observed in the hearts of transgenic mice carrying cyclin D2 DNA linked to a cardiomyocyte specific promoter, as described in Examples 2 and 3 below. In this
20 particular work, increases in proliferative potential in response to treatment with isoproterenol were observed in the left and right atria of the transgenic mice. In the right atrium of transgenic mice without *in vivo* isoproterenol treatment, the labeling index (thymidine incorporation analysis) was 0.09%. In corresponding mice with isoproterenol treatment, the right atrial labeling index was 0.29%.
25 Dramatically, in the left atrium, the labeling index was 0.31% without *in vivo* isoproterenol treatment, and 7.28% with isoproterenol treatment. Still further, as discussed in Example 8 below and illustrated in Figure 5, the culture of left atrial cardiomyocytes harvested from the transgenic cyclin D2 mice in the presence of isoproterenol provided a substantial increase in observed nuclei in culture. These
30 surprising discoveries provide access to methods in which the proliferative potential of cardiomyocytes can be increased *in vitro* or *in vivo* utilizing enhanced cyclin D2 activity in combination with administration of or treatment with a

suitable agent. In this regard, illustrative candidate agents for these purposes include pharmacologic agents, for example α -adrenergic and/or β -adrenergic receptor agonists, some of which are known to be hypertrophic agents, such as isoproterenol, epinephrine, norepinephrine, phenylephrine, and cyclic AMP
5 inducing agents, such as forskolin, and other pharmacological agents which increase levels of endogenous proteins or other factors having similar functions. Given the teachings herein, these and other pharmacologic agents may be readily screened and identified for their capacity to increase the proliferative potential of cardiomyocyte cells having enhanced cyclin D2 activity.

10

In one utilization of this discovery, cellular engraftment techniques can capitalize upon the increased cardiomyocyte proliferative potential in response to the agent. For instance, the agent may be incorporated in the culture medium during culture of the cells for subsequent implantation in the heart, and/or the cells
15 after implantation can be treated with the agent continuously or periodically to sustain the increased proliferative potential. In another utilization, cardiomyocytes in the heart of a mammal may be treated *in vivo* to enhance their cyclin D2 activity, and then the agent can be administered to the mammal to achieve an increase in proliferative potential.

20

Cellular engraftment and/or *in vivo* genetic modification in accordance with the invention can be used, for example, to deliver therapy to mammals, including humans. A variety of *ex vivo* cellular transplantation and implantation techniques and gene therapy techniques are thus contemplated as forming a part of the
25 invention. These may be used to target an improvement of the contractile function of the heart of the patient, for example in the treatment of contractile losses due to infarcts or cardiomyopathies.

The present discoveries also provide access to methods for screening the
30 activity of biologic, pharmacologic or other agents upon cardiomyocytes using cells of the invention. For example, access is provided to screening for co-factors or other conditions which, in combination with the enhanced cyclin D2 activity,

lead to increased cardiomyocyte proliferative potential as a baseline or in response to treatment with an agent. For example, the differential response of the heart chambers of the transgenic cyclin D2 mice described herein may be due to the presence of a co-factor in the left atrium that is not present or has a reduced presence in the right atrium or ventricles, and/or to the presence of an inhibitory protein in the right atrium or ventricles that is not present or has a reduced presence in the left atrium. The transgenic cyclin D2 mice described herein enable the use of automated techniques to discover the presence or absence, or relative levels, of such co-factors or inhibitory proteins in the various chambers of the heart. The identity of the cofactor(s) can be established, for example, based on its differential pattern of expression in responding versus non-responding cardiac samples using established techniques. For example, gene chip technology, differential display, and subtractive hybridization approaches, among others, can be exploited to identify those gene products which are differentially expressed in the responsive versus non-responsive cardiac tissue. The use of cardiomyocyte-enriched samples, as well as analogous samples from non-transgenic tissue, would permit screening against those non-specific factors which are also differentially expressed (i.e. those expressed in non-cardiomyocytes, and those which are generically induced in proliferating cells, respectively). Ventricular and/or right atrial cardiomyocytes can then be modified to enhance their ability to respond to agents as do the left atrial cardiomyocytes. For example, right atrial or right or left ventricular cardiomyocytes can be modified (e.g. transformed) *in vitro* or *in vivo* to increase expression of one or more proteins which are co-factors for cyclin D2 in responding to the agent, or can be so modified to decrease expression of inhibitory factors. In this manner, additional agent-responsive, proliferatively-enhanced cardiomyocytes are provided.

EXAMPLES

For the purpose of promoting a further understanding of the principles and features of the present invention, the following specific Examples are provided. It

will be understood that these Examples are intended to be illustrative, and not limiting, of the invention.

EXAMPLE 1

Preparation of a MHC-CYCD2 Fusion Gene

5 A MHC-CYCD2 transgene was constructed using the transcriptional regulatory sequences of the mouse α -cardiac myosin heavy chain (MHC) gene and a cDNA encoding mouse cyclin D2 (CYCD2) protein. The MHC promoter
10 (SEQ. I.D. NO. 5) consisted of 4.5 kb of 5' flanking sequence and 1 kb of the gene encompassing exons 1-3 up to but not including the initiation codon (Gulick, J. et al., *J. Biol. Chem.* 266:9180-9185 (1991)). The CYCD2 cDNA encompassed nucleotide residues #268-1143; Genbank Accession #M83749) (SEQ. I.D. No. 1), and was generated by reverse transcriptase-polymerase chain reaction (RT-PCR)
15 amplification of mouse heart RNA as described (Kim, K.K. et al., *J. Biol. Chem.* 269:22607-22613 (1994)). The integrity of the CYCD2 cDNA was confirmed by sequence analysis. The sequence of the sense primer was 5' GCT ATG GAG CTG CTG TGC TGC GAG GTG GAC 3' (SEQ. I.D. No. 7). The sequence of the antisense primer was 5' TCC TCA CAG GTC AAC ATC CCG CAC GTC TGT 3'
20 (SEQ. I.D. No. 8). The SV40 early region transcription terminator/polyadenylation site (nucleotide residues 2586-2452) was inserted downstream from the CYCD2 cDNA insert. The resulting transgene, designated MHC-CYCD2, was digested with Nru I and transgene insert was purified by agarose gel electrophoresis and eluted with Geneclean glass beads. A map of the
25 transgene is provided in Figure 1.

EXAMPLE 2

Generation of MHC-CYCD2 Transgenic Mice

30 The MHC-CYCD2 insert prepared in Example 1 was purified and injected into one cell embryos following standard procedures (Hogan, B., *Manipulating the Mouse Embryo*, Plainview, N.Y. Cold Spring Harbor Laboratory Press, p. 497 (1994)). The resulting 34 mice were screened for the presence of the transgene,
35 and 11 were identified as being transgenic. No obvious morbidity was apparent in

the founder mice. Eight mice randomly selected and placed in breeding cages ultimately gave rise to 4 transgenic lineages. Transgene expression was initially established by Western blot analysis (Figure 2). Heart homogenate was prepared from non-transgenic adult heart (-) as well as adult mice from MHC-CYCD2 lines designated 10, 9, 5 and 3. Samples from two individual mice from each lineage were analyzed. Hearts were homogenized in NP40 buffer (150 mM NaCl, 5 mM EDTA, 50 mM Tris-HCl pH 8.0, 1 µg/ml aprotinin, 1 µg/ml pepstatin, 1 µg/ml leupeptin, 50 µg/ml TLCK, 50 µg/ml PMSF, 100 µg/ml TPCK, 1% vol/vol Nonidet P-40). The homogenate was cleared by centrifugation at 40,000x g for 10 min, and the protein content of the supernatant was quantitated using a commercial assay (Bio-Rad, Richmond CA). Samples (60 µg/lane) were separated by size on 10% polyacrylamide gels under denaturing conditions, and electro-blotted to nitrocellulose (Hoefer Scientific, San Francisco CA) membranes. The filters were stained with 0.1% naphthol blue-black in 45% methanol, 10% acetic acid to assess the efficiency of transfer. For Western analysis, nonspecific binding was blocked by incubation in block buffer (5% nonfat dry milk, 3% BSA, 0.1% Tween, 1 x PBS) for 2 hr at room temperature. The antibody used in this study was a rat monoclonal antibody against cyclin D2 (Oncogene Science) at a working concentration of 2.5 µg/ml. Western blot analyses revealed that high levels of cyclin D2 protein were present in the hearts of the adult transgenic mice. Other Western blot analyses failed to detect elevated levels of cyclin D2 in all other tissues examined, consistent with the known myocardial specificity of the MHC promoter.

25

EXAMPLE 3

Demonstration of Increased Cardiomyocyte DNA Synthesis

30

A thymidine incorporation assay was used to determine if cardiomyocyte DNA synthesis persisted in adult transgenic MCH-CYCD2 animals. This testing also employed a second transgenic mouse line, designated MHC-nLAC. The MHC-nLAC mice express a nuclear localized β -galactosidase (β GAL) reporter gene exclusively in the cardiomyocytes (Soonpaa, M.H. et al., *Science* 264:98-101 (1994); Soonpaa, M.H. and L.J. Field, *Am. J. Physiol.* 272:H220-226 (1997)).

Accurate cardiomyocyte tritiated thymidine labeling indices can be readily obtained with the MHC-nLAC animals simply by screening for co-localization of β GAL activity and silver grains in autoradiographs of 5-bromo-4-chloro-3-indolyl-B-D-galactoside (X-GAL) stained heart sections. To monitor the effect of cyclin D2 overexpression on cardiomyocyte DNA synthesis, MHC-CYCD2 mice were crossed with MHC-nLAC mice and animals carrying either the MHC-nLAC transgene alone or both transgenes were identified and sequestered. When the mice reached 11 weeks of age, they received a single injection of tritiated thymidine and were sacrificed four hours later. The hearts were removed, sectioned, stained with X-GAL and processed for autoradiography. Ventricular cardiomyocyte labeling indices of 0.24% were observed for the double transgenic mice, whereas no DNA synthesis was observed in the MHC-nLAC control group (about 30,000 nuclei were scored for each group, $n = 5$ mice). DNA synthesis was also observed in the atria of the double transgenic mice, with the results presented in Table 3 below. In light of the sustained cardiomyocyte DNA synthesis observed in the adult MHC-CYCD2 mouse hearts, a series of experiments was initiated to ascertain how the transgenic myocardium would respond to cardiac hypertrophy. Osmotic mini-pumps (Model 2001, Alzet, Palo Alto, California, flow rate of 1 μ l per hour) filled with saline or 0.028 g/ml isoproterenol in saline were implanted through a small longitudinal incision between the scapulae. 8 control mice (MHC-nLAC) and 8 cyclin D2 mice (MHC-nLAC/MHC-CYCD2 double transgenics) were used. In the cyclin expressing mice, continuous administration of isoproterenol for 7 days resulted in a 47.6% increase in heart weight/body weight. In control mice, isoproterenol treatment resulted in a 28% increase in heart weight/body weight as compared to saline treated animals.

Prior to sacrifice, the experimental and control mice received a bolus injection of tritiated thymidine to permit assessment of cardiomyocyte DNA synthesis. After a 4 hour chase, the animals were sacrificed, and the hearts were harvested, cryoprotected, sectioned, stained with X-GAL and subjected to autoradiography. Once again, cardiomyocyte DNA synthesis was measured by scoring the presence of silver grains over β GAL positive nuclei. A huge increase

in the left atria cardiomyocyte labeling index was observed in the MHC-CYCD2 mice following isoproterenol treatment (0.31% for the non-isoproterenol-treated group versus 7.28% for the isoproterenol-treated group). DNA synthesis in the right atrium of MHC-CYCD2 mice was moderately increased, and in the ventricle of these mice was moderately decreased. Isoproterenol treatment had no effect on cardiomyocyte DNA synthesis in the non-cyclin expressing control group.

TABLE 3

| Mice | Right Atrium | Left Atrium | Ventricle |
|---------------|--------------|-------------|-----------|
| Control | | | |
| Uninjured | 0% | 0% | 0% |
| Isoproterenol | 0% | 0% | 0% |
| MHC-CYCD2 | | | |
| Uninjured | 0.09% | 0.31% | 0.24% |
| Isoproterenol | 0.29% | 7.28% | 0.11% |

10

The above data demonstrate that transgenic animals expressing cyclin D2 have sustained atrial and ventricular cardiomyocyte DNA synthesis, and that the rate of atrial cardiomyocyte DNA synthesis is dramatically increased in response to the administration of isoproterenol. Pulse chase experiments were employed to determine the fate of the cardiomyocytes synthesizing DNA. Once again, MHC-CYCD2 mice were crossed with MHC-nLAC mice. The MHC-nLAC mice express a nuclear localized β -GAL reporter exclusively in cardiomyocytes. Mice from this cross carrying either the MHC-nLAC transgene alone or both the MHC-nLAC and MHC-CYCD2 transgenes were identified and sequestered. At 11 weeks of age, myocardial hypertrophy was induced by isoproterenol infusion with Alzet minipumps (minipump model 2001, Alzet, Palo Alto CA; flow rate of 1 μ l/hr, 0.028 g/ml isoproterenol). After 7 days of isoproterenol infusion, the control (MHC-nLAC) and experimental (MHC-nLAC/MHC-CYCD2 double transgenic) mice received a single injection of 3H-thymidine (200 uCi I.P. at 28

25

Ci/mM, Amersham, Arlington Heights, IL), and were sacrificed either 4 hours (pulse, Figure 3A) or 72 hours (chase, Figure 3B) later. The hearts were removed, cryoprotected in 30% sucrose, embedded and sectioned at 10 μ m using standard histologic techniques. The sections were post-fixed in formaldehyde:glutaraldehyde (1:1) and overlaid with 1 mg/ml X-GAL, 5 mM potassium ferricyanide, 5 mM potassium ferrocyanide and 2 mM magnesium chloride in PBS. The sections were counter-stained with DAPI, and washed three times in PBS. After drying, stained slides were coated with photographic emulsion (Ilford L4, Polysciences, Warrington PA) diluted 1:1 with water, drained, and placed in a light-tight box for four days at 4°C. Slides were then developed in Kodak D-19 (Rochester NY) for four minutes, washed in water, and fixed in 30% sodium thiosulfate for at least four minutes. Slides were further processed by washing in H₂O and by dehydration through graded ethanols and xylene, followed by application of a coverslip. Cardiomyocyte DNA synthesis was scored by the co-localization of BGAL activity (blue staining) and silver grains. The high DNA synthesis labeling index seen following the three day chase period indicated that the cardiomyocytes which undergo DNA synthesis were viable (in contrast to pronounced apoptosis observed with E1A and E2F gene transfer into cardiomyocytes, see Kirshenbaum et al., *J. Biol. Chem.* 270:7791-7794 (1995); Kirshenbaum et al., *Dev. Biol.* 179:402-411 (1996)). Cardiomyocyte DNA synthesis following isoproterenol-induced hypertrophy in MHC-CYCD2/MHC-nLAC transgenic mice is evident from the presence of silver grains over blue nuclei (arrows, Figure 3A). In Figure 3B, the appearance of silver grains over paired blue nuclei is indicative of DNA synthesis followed by nuclear division (or kariokinesis, see paired arrows).

EXAMPLE 4

Analysis of Levels of Various Proteins in MHC-CYCD2 Transgenic Mice

Western blots were used to analyze protein expression levels in adult MHC-CYCD2 mice and their non-transgenic litter mates. Hearts were homogenized in NP40 buffer (150 mM NaCl, 5 mM EDTA, 50 mM Tris-HCl pH

8.0, 1 µg/ml aprotinin, 1 µg /ml pepstatin, 1 µg /ml leupeptin, 50 µg /ml TLCK, 50 µg /ml PMSF, 100 µg /ml TPCK, 1% vol/vol Nonidet P-40). The homogenate was cleared by centrifugation at 40,000x g for 10 min, and the protein content of the supernatant was quantitated using a commercial assay (Bio-Rad, Richmond CA). Samples were separated by size on 10% polyacrylamide gels under denaturing conditions as described, and electro-blotted to nitrocellulose (Hoefer Scientific, San Francisco CA) membranes. The filters were stained with 0.1% naphthol blue-black in 45% methanol, 10% acetic acid to assess the efficiency of transfer. For Western analysis, nonspecific binding was blocked by incubation in block buffer (5% nonfat dry milk, 3% BSA, 0.1% Tween, 1 x PBS) for 2 hr at room temperature. Commercial antibodies were used for each protein analyzed. Conditions (i.e. dilution, length of reaction, secondary antibody, etc) were according to the manufacturer's recommendations. The results are presented in Table 4 below, in which higher numbers of the symbol "+" indicate higher levels of protein, and the symbol "-" indicates none detected.

TABLE 4

| Marker | Nontransgenic | Transgenic |
|-----------|---------------|------------|
| Cyclin D2 | + | +++++ |
| Cyclin D1 | + | + |
| Cyclin D3 | + | + |
| PCNA | + | +++ |
| CDC2 | - | - |
| CDK2 | + | + |
| CDK4 | + | ++++ |
| CDK6 | + | + |
| Dmp 1 | + | + |
| pRb | - | +++ |
| p107 | + | ++ |
| p130 | + | ++ |

These results demonstrate that upregulation of cyclin D2 in the transgenic mice was sufficient to elicit increased expression in a number of gene products required for cell cycle progression.

EXAMPLE 5

Analysis of Cell Cycle Protein Level Changes in Response to Isoproterenol

- 5 Myocardial hypertrophy was induced by isoproterenol infusion with Alzet minipumps in adult MHC-CYCD2 mice and their non-transgenic siblings (minipump model 2001, Alzet, Palo Alto CA; flow rate of 1 μ l/hr, 0.028 g/ml isoproterenol). Hearts were harvested after 7 days of isoproterenol infusion and processed for Western blot analysis using procedures as described in Example 4.
- 10 The results are presented in Table 5 below. Again, higher numbers of the symbol "+" indicate higher levels of protein, and the symbol "-" indicates none detected.

TABLE 5

| Marker | NonTransgenic (-Iso) | NonTransgenic (+Iso) | Transgenic (-Iso) | Transgenic (+Iso) |
|-----------|-------------------------|-------------------------|----------------------|----------------------|
| Cyclin D2 | + | + | +++++ | +++++ |
| PCNA | + | ++ | ++ | ++++ |
| CDC2 | - | ++ | - | ++++ |

5

EXAMPLE 6Culture of CYCD2 Versus Control Cardiomyocytes

Hearts from MHC-CYCD2 transgenic mice or their non-transgenic siblings were harvested at the age indicated, and the left atria were dissected and digested in PBS (37°C, 60 min) containing 0.17% collagenase (Type I, Worthington Biochemical, Freehold NJ). Cells were then triturated with a Pasteur pipette and plated at a density of 1×10^5 cells per chamber slide in DMEM medium containing 10% FBS supplemented with $1 \mu\text{m}$ isoproterenol. Plating was scored by the presence or absence of contractile cells 72 hours later. The results are presented in Table 6 below, in which "+" indicates a successful culture and "-" indicates an unsuccessful culture.

TABLE 6

20

| Postnatal Stage | Nontransgenic | Transgenic |
|-----------------|---------------|------------|
| Day 1 | + | + |
| Day 8 | - | + |
| Day 14 | - | + |
| Day 21 | - | + |

These results demonstrate that increased cyclin D2 activity can be used to achieve dramatic improvement in the capacity to culture cardiomyocyte cells.

25

EXAMPLE 7

Demonstration of Increased Cell Numbers in Left and Right Atria

Left and right atria from neonatal day 14 MHC-CYCD2 transgenic mice and their non-transgenic siblings were harvested and digested in PBS (37°C, 60 min) containing 0.17% collagenase (Type I, Worthington Biochemical, Freehold NJ). Cells were then triturated with a Pasteur pipette and counted directly with a hemocytometer. The results are graphically represented in Figure 4, which shows increased cell numbers in the left and right atria of MHC-CYCD2 mice as compared to nontransgenics.

10

EXAMPLE 8

Demonstration of Increased Cell Nuclei (Kariokinesis) in Cultures with Isoproterenol

Left atria from neonatal day 14 MHC-CYCD2 transgenic mice were harvested and digested in PBS (37°C, 60 min) containing 0.17% collagenase (Type I, Worthington Biochemical, Freehold NJ). Cells were then triturated with a Pasteur pipette and plated at a density of 1×10^5 cells per chamber slide. Cells were cultured in DMEM supplemented with 10% FBS. In some cases, the media also contained isoproterenol (1 μ m). After 72 hrs., the slides were fixed in glutaraldehyde-formaldehyde (1:1) and overlaid with 1 mg/ml X-GAL, 5 mM potassium ferricyanide, 5 mM potassium ferrocyanide and 2 mM magnesium chloride in PBS. The number of blue nuclei were counted directly on a microscope. Figure 5 provides a bar graph of the results, showing that culture of cardiomyocytes from the left atria of MHC-CYCD2 transgenic mice in the presence of isoproterenol leads to a substantial increase in the number of cardiomyocyte nuclei in the culture.

15

20

25

EXAMPLE 9

Demonstration of Cell Proliferation (Cytokinesis) in CYCD2 Cardiomyocytes

5 Left atria from neonatal day 14 MHC-CYCD2 transgenic mice were harvested, digested, triturated, plated and cultured in DMEM supplemented with 10% FBS and isoproterenol (1 μ m), as described in Example 8. After 72 hrs., the slides were fixed in acetone and processed for myosin heavy chain immune reactivity using monoclonal antibody MF-20. Signal was developed using a
10 FITC-conjugated anti-mouse IgG secondary antibody. Nuclei were counter stained with Hoechst 3334. Figure 6A shows a cardiomyocyte undergoing cytokinesis (FITC signal, green cube); Figure 6B shows the same field though for Hoechst staining (blue cube).

EXAMPLE 10

Demonstration of Cell Cycle Activation in Cautery Injury Model

15 In this Example it was demonstrated that the cell cycle of cardiomyocytes with increased cyclin D2 levels is activated in a cautery injury model which
20 mimics myocardial infarction. 11 week old MHC-nLAC control or MHC-nLAC/MHC-CYCD2 double transgenic mice were anesthetized (2.5% Avertin, 0.015 ml/g body weight, I.P., Fluka Chemicals, Ronkonkoma NY) and intubated (Small Animal Respirator, 70 cycles/second, tidal pressure 1.2 k Pascals, Narco Biosystems, Houston TX). The heart was exposed *via* an incision at the third
25 intercostal space, and the myocardium was cauterized midway between the apex and base of the heart using a Medi-Pak surgical cautery (General Medical Corporation Richmond VA). After cauterization, the incision was closed, the pneumothorax evacuated, and the mice allowed to recover from anesthesia on a heating pad maintained at 37°C. The mortality rate for the procedure was <5%.
30 All animal manipulations were performed in accordance with institutional guidelines. 7 days after injury, the experimental and control mice received a single injection of 3H-thymidine (200 μ Ci I.P. at 28 Ci/mM, Amersham, Arlington Heights, IL), and were sacrificed 4 hours later. The hearts were

removed, cryoprotected in 30% sucrose, embedded and sectioned at 10 μ m using standard histologic techniques. To localize regions of myocardial damage, sections were stained with Hemotoxylin and Eosin (H and E) according to the manufacturer's specifications (Sigma). To localize cardiomyocyte nuclei, sections
5 were post-fixed and overlaid with 1 mg/ml X-GAL, 5 mM potassium ferricyanide, 5 mM potassium ferrocyanide and 2 mM magnesium chloride in PBS. The sections were counter-stained with DAPI, and after drying autoradiographic emulsion (Ilford L4, Polysciences, Warrington PA) diluted 1:1 with water, drained, and placed in a light-tight box for 4 days at 4°C. Slides were
10 then developed in Kodak D-19 (Rochester NY) for four minutes, washed in water, and fixed in 30% sodium thiosulfate for at least four minutes. Slides were further processed by washing in H₂O and by dehydration through graded ethanols and xylene, followed by application of a coverslip.

15 Cardiomyocyte DNA synthesis in MHC-CYCD2 transgenic mice was also monitored following cautery injury, which mimics myocardial infarction. The left ventricular free wall was injured by cauterization. Gross examination of the hearts 7 days post-injury revealed the presence of a necrotic zone at the site of cauterization. In addition, pronounced blanching of the myocardium was evident
20 in the region distal to and apically located from the cauterization site. The appearance and location of the blanching was consistent with ischemic myocardial damage resulting from disruption of the underlying vasculature at the site of cauterization. The extent of myocardial damage was readily detected in histologic sections; as much as 50% of the left ventricular free wall was affected.
25 To monitor DNA synthesis, injured MHC-nLAC transgenic animals (controls) and injured MHC-nLAC/MHC-CYCD2 transgenic animals received a single injection of tritiated thymidine. The hearts were then harvested, sectioned, stained with X-GAL and processed for autoradiography. Figure 7A shows a single synthetic ventricular cardiomyocyte nucleus (arrow) in the peri-necrotic zone of an MHC-
30 nLAC/MHC-CYCD2 transgenic mouse located apically from the cauterization site. Figure 7B shows the peri-necrotic zone from a different MHC-nLAC/MHC-CYCD2 transgenic animal; the arrows point to two cardiomyocyte nuclei

undergoing DNA synthesis. 0.53% of the cardiomyocytes in the peri-necrotic zone were synthesizing DNA in the MHC-nLAC/MHC-CYCD2 transgenic animals (3,202 cells were screened). In contrast, 0% of the cardiomyocytes in the peri-necrotic zone were synthesizing DNA in the MHC-nLAC control animals (3,400 cells were screened). Thus, an increase in cardiomyocyte DNA synthesis is observed in the cyclin D2 expressing hearts in response to injury. Moreover, the overall rate of cardiomyocyte DNA synthesis in the MHC-CYCD2 hearts is in vast excess to that in the injured control hearts (which was undetectable in the assay performed).

10

EXAMPLE 11

STK-rMHC-Switch-CycD2 Virus

This Example describes a virus designed to provide inducible expression of cyclin D2 in adult cardiac tissue or cardiomyocytes useful for engraftment. The known STK virus is utilized. STK is a 3rd generation Adenovirus which has been modified so as not to encode any Adenoviral proteins. This design limits any host immune response against cells transduced with the virus in vivo.

With reference to Figure 8, the virus contains two transcriptional units. The first transcriptional unit utilizes the rat alpha-cardiac myosin heavy chain (rMHC) promoter to target cardiac specific expression of the known "Gene-Switch" transcription factor. The polyadenylation and transcription termination sequences from the bovine growth hormone (bGH) gene is inserted down-stream of the Gene-Switch sequence. Cardiomyocytes transfected with this virus will express the Gene-Switch protein. In contrast non-cardiomyocytes transfected with this virus will not express the "Gene-Switch" protein, as the rMHC promoter is not active in non-cardiomyocytes. The Gene-Switch transcription factor is only active in the presence of an appropriate ligand (as for example Ru486).

30

The second transcriptional unit in the virus utilizes a 4xUAS TATA promoter to target expression of cyclin D2 (CycD2). The polyadenylation and transcription termination sequences from the SV40 early region is inserted down-

stream from the CycD2 sequence. Transcription from the 4xUAS TATA promoter is dependent upon the presence of active Gene-Switch protein.

Thus constructed, the system is used and functions as follows. Heart tissue and/or cardiomyocytes to be used for engraftment are virally transduced with the STK-rMHC-Switch-CycD2 virus. Transfected cardiomyocytes express the Gene-Switch protein, which is inactive in the absence of ligand. Non-cardiomyocytes do not express the Gene-Switch protein. To activate the system, ligand is administered. This results in the activation of Gene-Switch transcription factor in cardiomyocytes. The activated Gene-Switch transcription factor initiates transcription at the 4xUAS TATA promoter. This in turn results in the synthesis of CycD2 mRNA, and ultimately CycD2 protein. Thus, the system provides for regulated synthesis of Cyclin D2. It will be used to direct gene expression (and consequently cell cycle activation) in adult cardiomyocytes.

EXAMPLE 12

Text for the STK-rMHC-CycD2-nLAC virus:

This Example describes the design of a virus useful to provide constitutive expression of cyclin D2 in adult cardiac tissue or other cardiomyocytes. The STK virus is utilized, as in Example 11 above. With reference now to Figure 9, a single bi-cistronic transcriptional unit is utilized. The rat alpha-cardiac myosin heavy chain (rMHC) promoter (see *American Journal of Physiology*, Vol. 262: H1867-H1876 (1992)) is used to target cardiac specific expression of Cyclin D2 (CycD2). An internal ribosomal entry site is located downstream of the CycD2 sequences. This is followed by sequences encoding a marker gene (nLAC, a nuclear localized beta-galactosidase). Thus cardiomyocytes transfected with this virus will express a bi-cistronic transcript which encodes both the CycD2 and marker gene sequences. In contrast non-cardiomyocytes transfected with this virus will not express the bi-cistronic transcript, as the rMHC promoter is not active in non-cardiomyocytes. Thus, the system provides for constitutive

synthesis of Cyclin D2 in adult cardiomyocytes. The presence of the marker gene will permit discrimination between infected and non-infected cardiomyocytes.

5 While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

10 All publications cited herein are indicative of the level of skill in the art and are hereby incorporated by reference as if each had been individually incorporated by reference and fully set forth.

WHAT IS CLAIMED IS:

1. A method for increasing the proliferative potential of a cardiomyocyte cell, comprising increasing the level of cyclin D2 activity in the
5 cardiomyocyte cell so as to increase the proliferative potential of the cardiomyocyte cell.

2. The method of claim 1, comprising:
providing cardiomyocyte cells in a culture medium;
10 introducing nucleic acid into the cardiomyocyte cells, said nucleic acid having a sequence of nucleotides encoding a cyclin D2 protein; and
culturing the cardiomyocyte cells under conditions suitable for expression of said cyclin D2 protein.

15 3. The method of claim 1, wherein said introduced nucleic acid has a nucleotide sequence corresponding to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3, or a nucleotide sequence having substantial identity thereto.

20 4. The method of claim 3, wherein said introduced nucleic acid has a nucleotide sequence corresponding to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3, or said introduced nucleic acid hybridizes to nucleic acid having nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3 under stringent conditions, and encodes a protein having cyclin D2 activity.

25 5. The method of claim 4, wherein said nucleotide sequence is operably linked to a promoter.

6. The method of claim 4, wherein said promoter is a constitutive promoter.

30 7. The method of claim 4, wherein said promoter is an inducible promoter.

8. The method of claim 4, wherein said promoter is a cardiomyocyte specific promoter.

5 9. The method of claim 1, wherein said cardiomyocyte cell is a mammalian cardiomyocyte cell.

10 10. A method for culturing cardiomyocyte cells, comprising:
providing cardiomyocyte cells in a culture medium, said cardiomyocyte
cells having an increased intracellular level of cyclin D2; and
culturing the cardiomyocyte cells in said culture medium.

11. The method of claim 10, wherein said cardiomyocyte cells have introduced nucleic acid encoding a cyclin D2 protein operably linked to a
15 constitutive promoter.

12. The method of claim 10, wherein said cardiomyocyte cells have introduced nucleic acid encoding a cyclin D2 protein operably linked to an inducible promoter.

20

13. The method of claim 10, wherein said cardiomyocyte cells have introduced nucleic acid encoding a cyclin D2 protein operably linked to a cardiomyocyte specific promoter.

25 14. The method of any of claims 10-13, wherein said introduced nucleic acid is DNA having a nucleotide sequence corresponding to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3, or a nucleotide sequence having substantial identity thereto.

30 15. The method of any of claims 10-13, wherein said introduced nucleic acid encodes a protein having the amino acid sequence of SEQ. I.D. NO. 2 or SEQ. I.D. NO. 4, or a polypeptide having an amino acid sequence at least 70%

identical to the amino acid sequence of SEQ. I.D. NO. 2 or SEQ. I.D. NO. 4, and which exhibits cyclin D2 activity.

16. The method of any of claims 10-15, wherein said culturing
5 includes culturing in the presence of a pharmacologic agent that induces an increase in the proliferative potential of the cells..

17. The method of any of claims 10-16, wherein said cardiomyocytes
10 are mammalian cardiomyocytes.

18. The method of any of claims 10-17, wherein said cardiomyocytes
are human cardiomyocytes.

19. The method of any of claims 10-17, wherein said cardiomyocytes
15 are murine cardiomyocytes.

20. A cardiomyocyte cell having introduced nucleic acid encoding a
cyclin D2 protein.

20 21. The cell of claim 20, wherein said introduced nucleic acid has a
nucleotide sequence corresponding to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or
SEQ. I.D. NO. 3, or a nucleotide sequence having substantial identity thereto.

22. The cell of claim 21, wherein said introduced nucleic acid encodes
25 a polypeptide having the amino acid sequence of SEQ. I.D. NO. 2 or SEQ. I.D.
NO. 4, or a polypeptide having an amino acid sequence at least 70% identical to
the amino acid sequence of SEQ. I.D. NO. 2 or SEQ. I.D. NO. 4, and which
exhibits cyclin D2 activity.

30 23. The cell of any of claims 20-22, wherein said nucleotide sequence
is operably linked to a promoter.

24. The cell of claim 23, wherein said promoter is a constitutive promoter.

5 25. The cell of claim 23, wherein said promoter is an inducible promoter.

26. The cell of claim 23, wherein said promoter is a cardiomyocyte specific promoter.

10 27. The cell of any of claims 20-26, wherein said cardiomyocyte cell is a mammalian cardiomyocyte cell.

15 28. The cell of any of claims 20-26, wherein said cardiomyocyte cell is a human cardiomyocyte cell.

29. A nucleic acid construct having a sequence of nucleotides encoding a cyclin D2 protein, said sequence of nucleotides operably linked to an inducible promoter.

20 30. The construct of claim 29, wherein said sequence of nucleotides corresponds to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3, or is a sequence of nucleotides having substantial identity thereto.

25 31. The construct of claim 29, wherein said sequence of nucleotides corresponds to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3, or is a sequence of nucleotides which hybridizes to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3 under stringent conditions and which encodes a polypeptide having cyclin D2 activity.

30 32. A nucleic acid construct having a sequence of nucleotides encoding a cyclin D2 protein operably linked to a cardiomyocyte-specific promoter.

33. The construct of claim 32, wherein said sequence of nucleotides corresponds to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3, or is a sequence of nucleotides having substantial identity thereto.

5 34. The construct of claim 32, wherein said sequence of nucleotides corresponds to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3, or is a sequence of nucleotides which hybridizes to nucleotides 4 to 870 of SEQ. I.D. NO. 1 or SEQ. I.D. NO. 3 under stringent conditions and which encodes a protein having cyclin D2 activity.

10 35. A method for increase the proliferative potential of myocardial cells in a mammal, comprising:

increasing the level of cyclin D2 in cardiomyocytes in myocardial tissue of the mammal so as to increase the proliferative potential of the cardiomyocytes.

15 36. The method of claim 35, which comprises transfecting said cardiomyocytes with an expression vector having nucleic acid encoding a cyclin D2 protein operably linked to a promoter.

20 37. The method of claim 36, wherein said promoter is a constitutive promoter.

38. The method of claim 36, wherein said promoter is an inducible promoter.

25 39. The method of claim 36, wherein said promoter is a cardiomyocyte specific promoter.

30 40. The method of any of claims 35-39, also comprising administering to the mammal an agent that increases activation of the cell cycle in the transfected cardiomyocytes.

41. The method of claim 40, wherein the pharmacologic agent is an adrenergic receptor agonist.

42. The method of claim 41, wherein the receptor agonist is a β -
5 adrenergic receptor agonist.

43. A method for providing proliferative cardiomyocytes in a mammal, comprising:
providing cardiomyocytes in a mammal, said cardiomyocytes responsive
10 to an agent to increase the proliferative capacity of said cardiomyocytes; and
administering said agent to the mammal so as to increase the proliferative capacity of the cardiomyocytes.

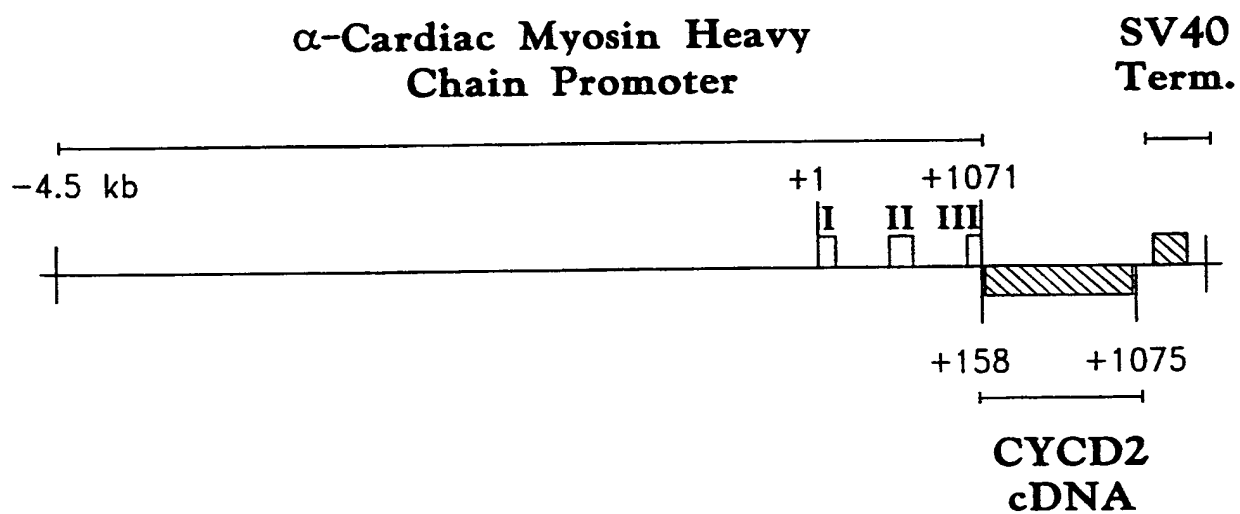
44. The method of claim 43, wherein said cardiomyocytes contain
15 introduced DNA encoding a cyclin D2 protein.

45. The method of claim 44, wherein said introduced DNA is operatively linked to an inducible promoter, and said agent causes induction of said inducible promoter.
20

46. A transgenic, non-human mammal having cardiomyocytes expressing introduced DNA encoding a cyclin D2 protein, the cardiomyocytes thereby exhibiting an activated cell cycle.

25 47. A modified D-type cyclin protein having removed therefrom one or more phosphorylation sites present in its native form, the modified D-type cyclin exhibiting the capacity to provide to mammalian cardiomyocytes an increased proliferative potential and sustained DNA synthesis when subjected to injurious stimuli.

30 48. A nucleic acid molecule encoding a modified D-type cyclin of claim 47.

Structure of the MHC-CYCD2 transgene.***Fig. 1***

2/10

Western blot analysis of cyclin D2
expression in MHC-CYCD2 transgenic hearts

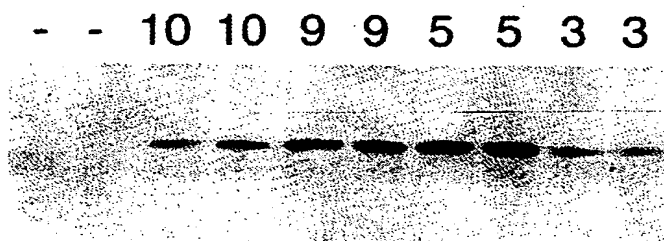


FIGURE 2

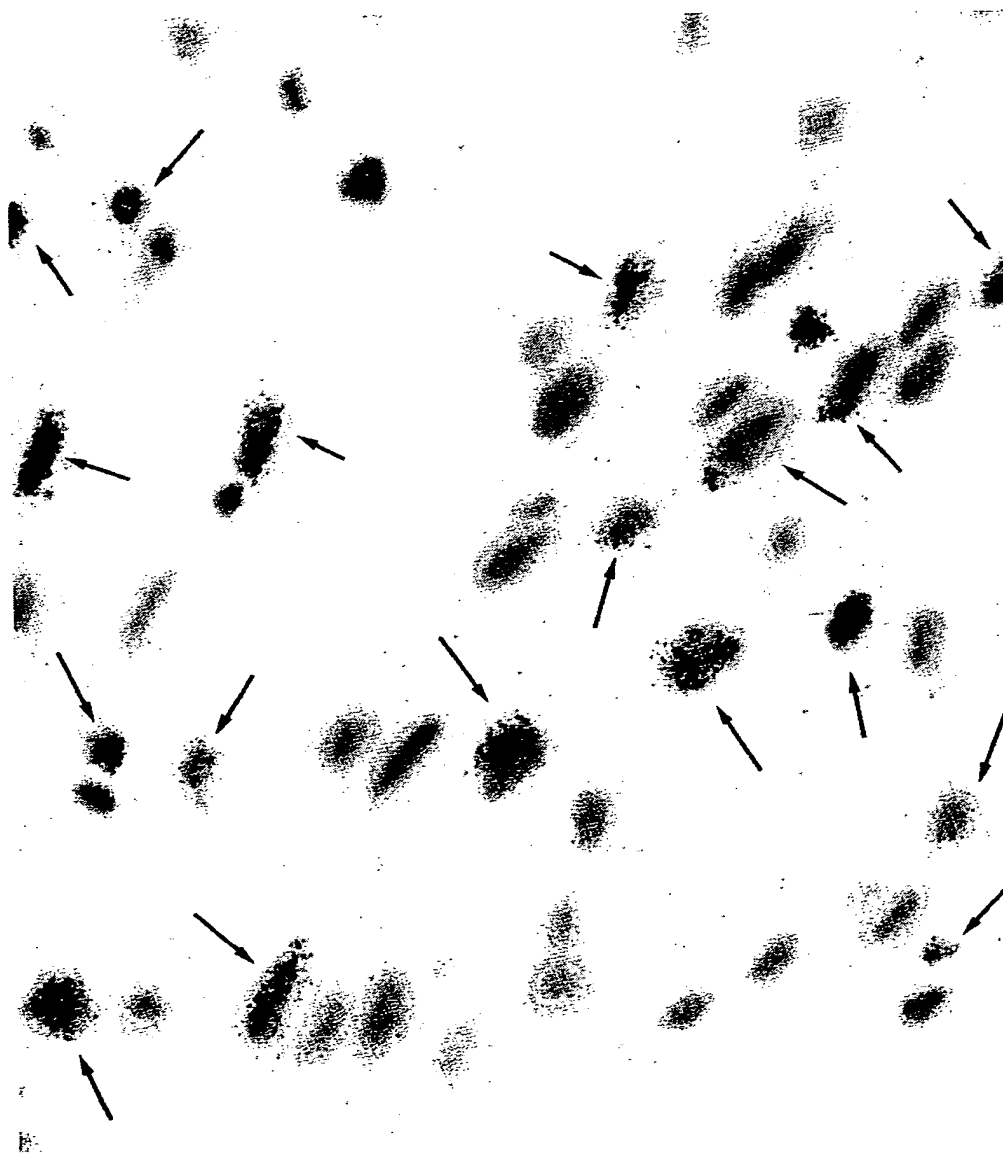


FIGURE 3A

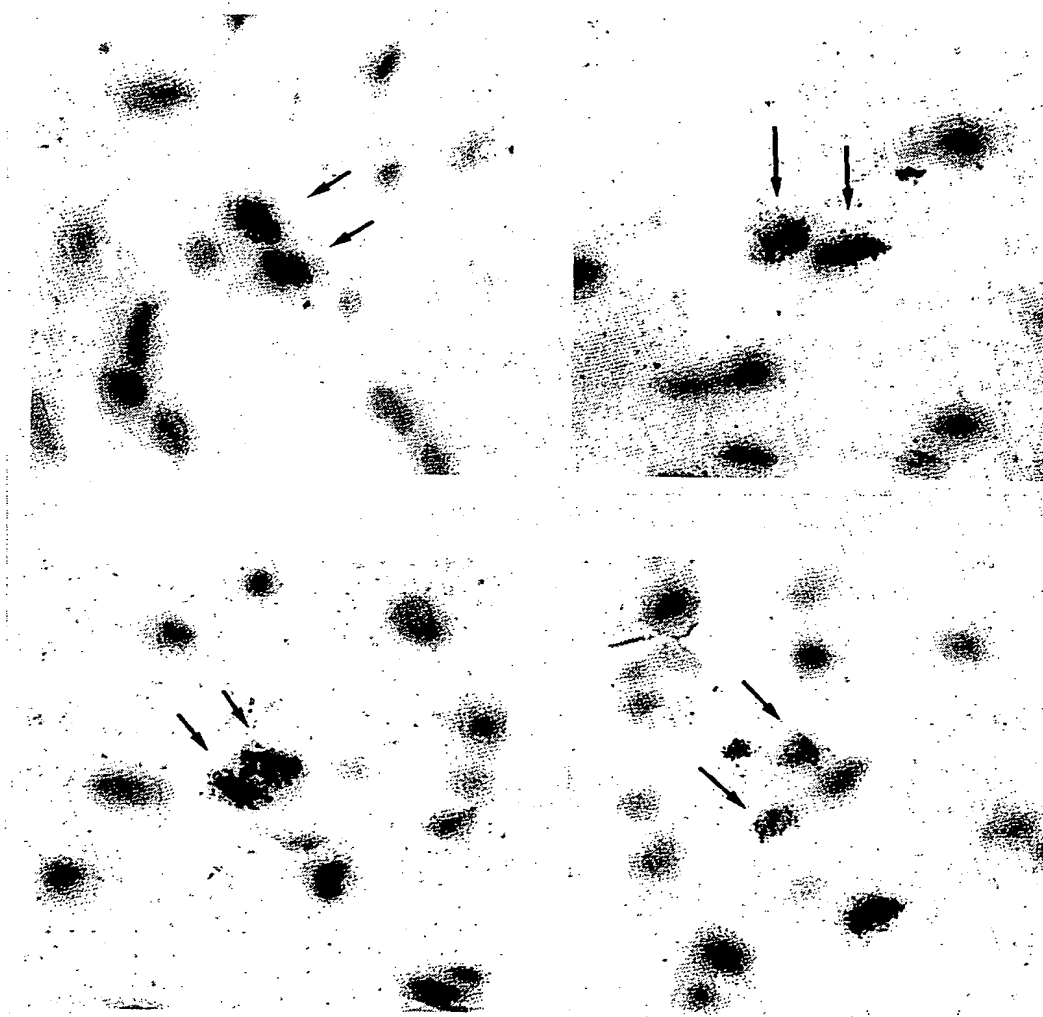
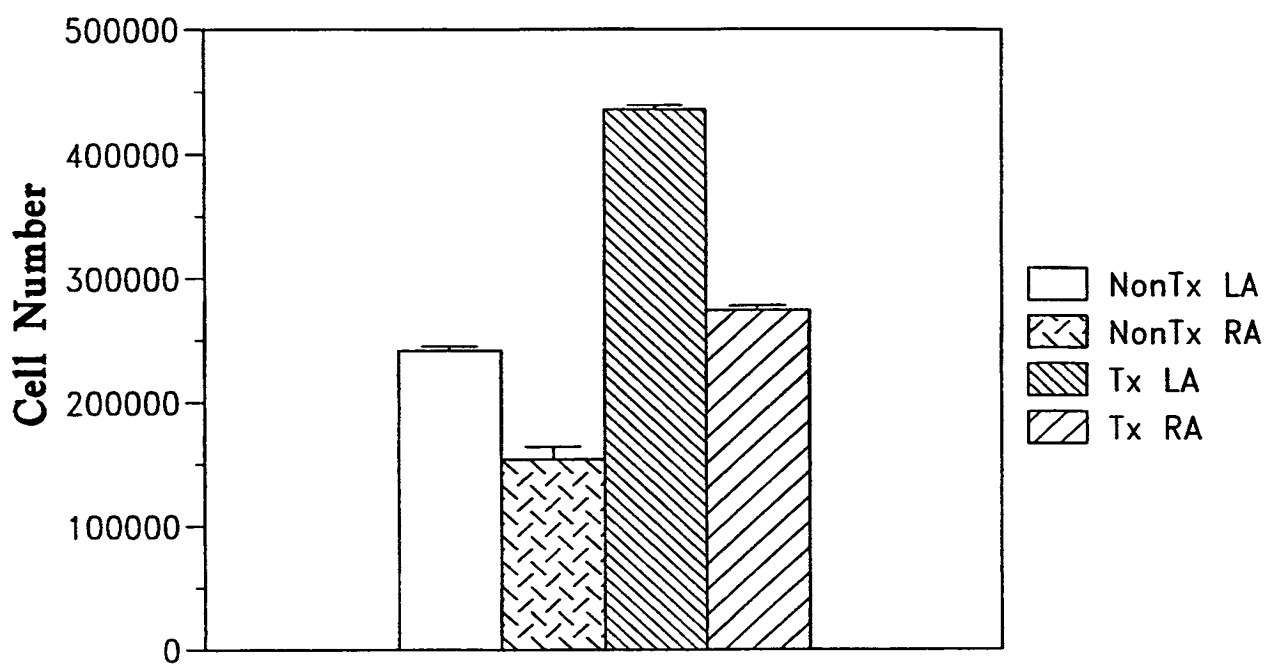
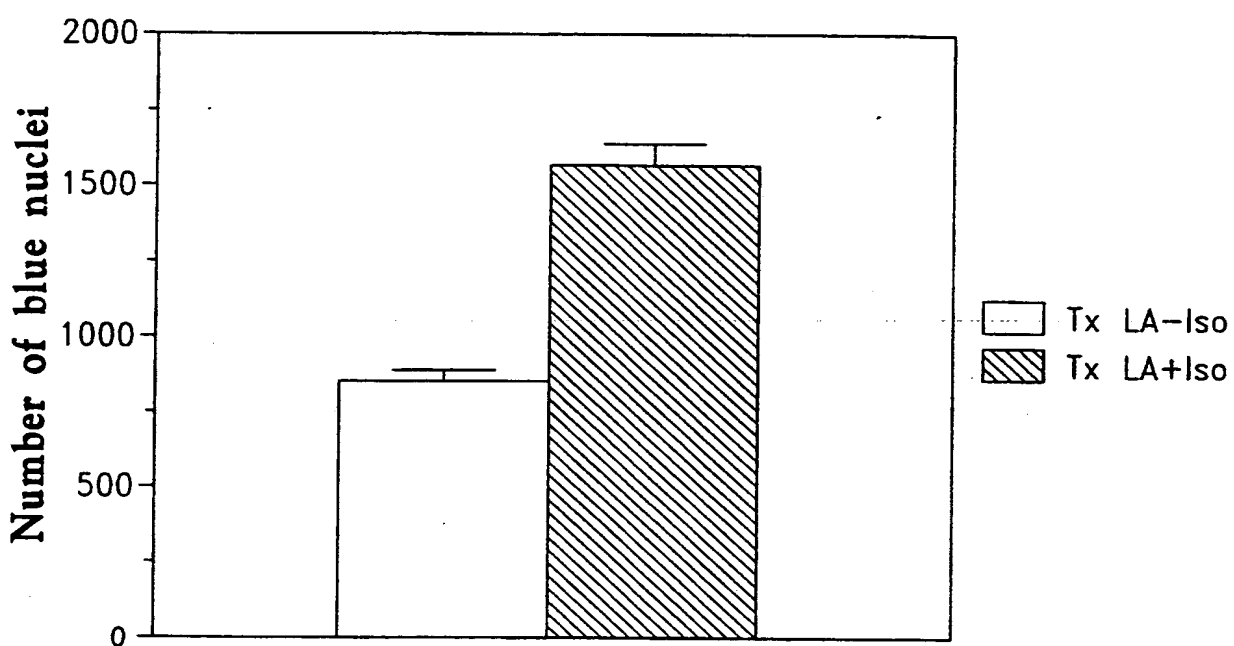


FIGURE 3B

**Fig. 4**

**Fig. 5**

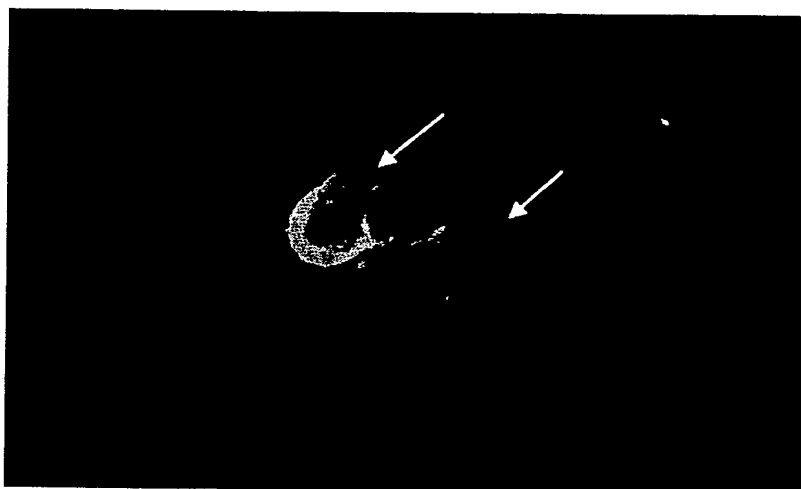


FIGURE 6A



FIGURE 6B

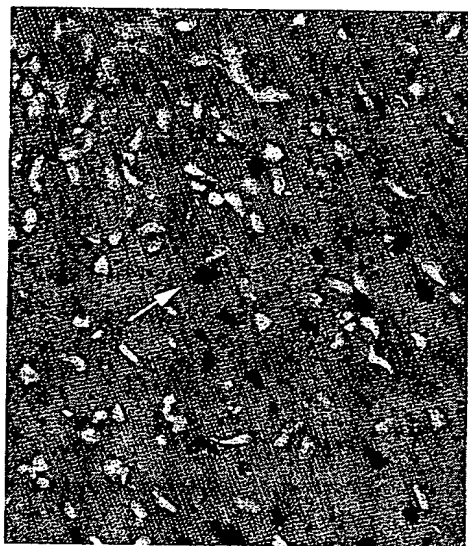


FIGURE 7A

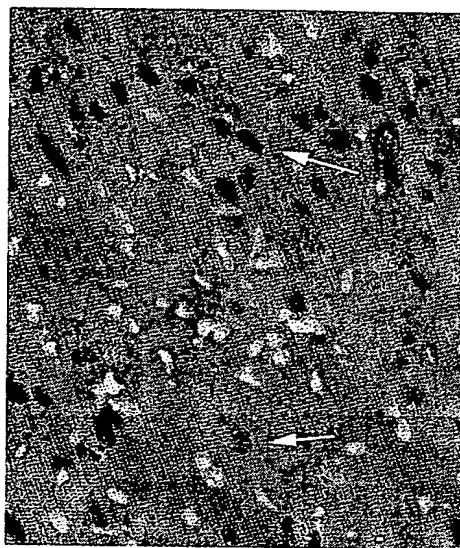


FIGURE 7B

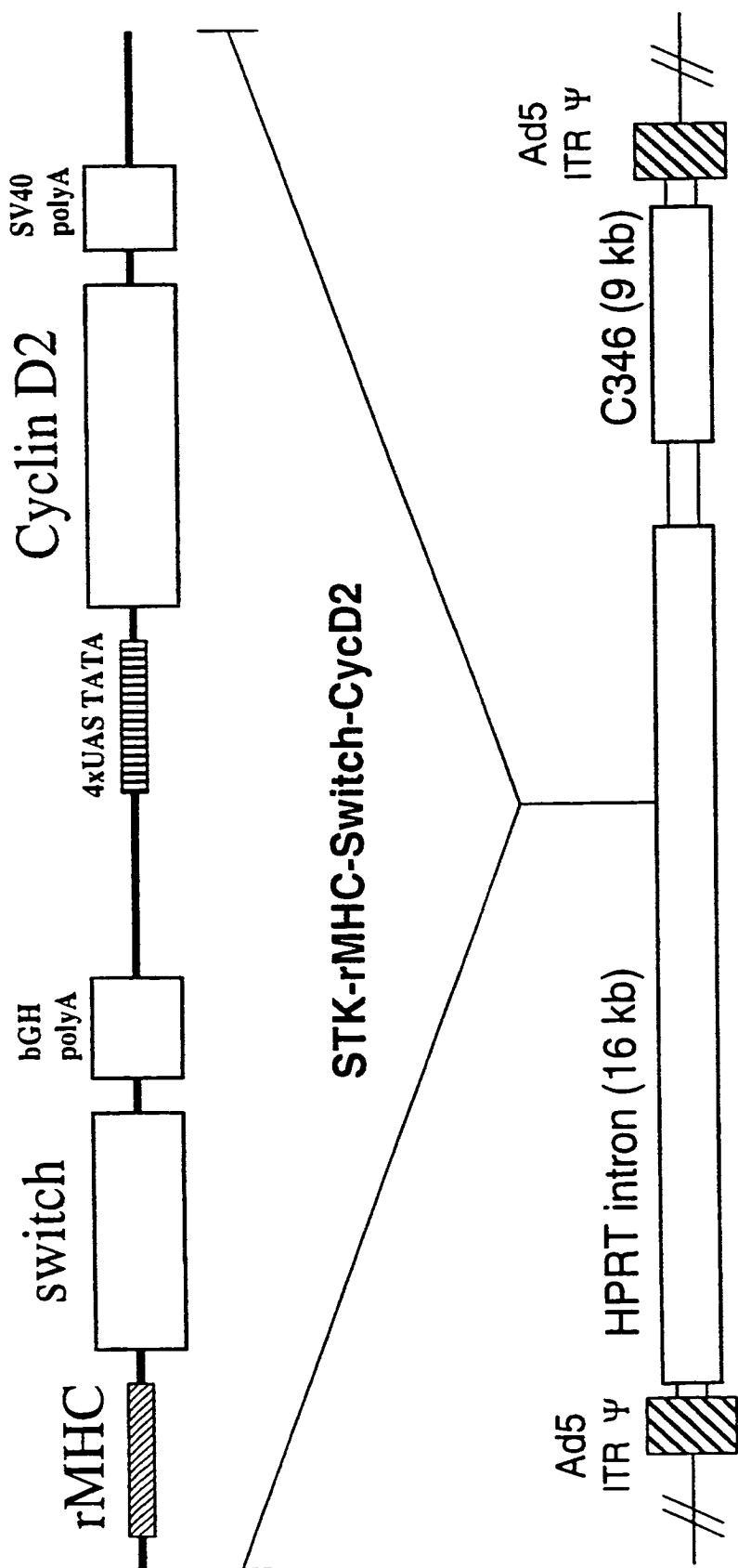
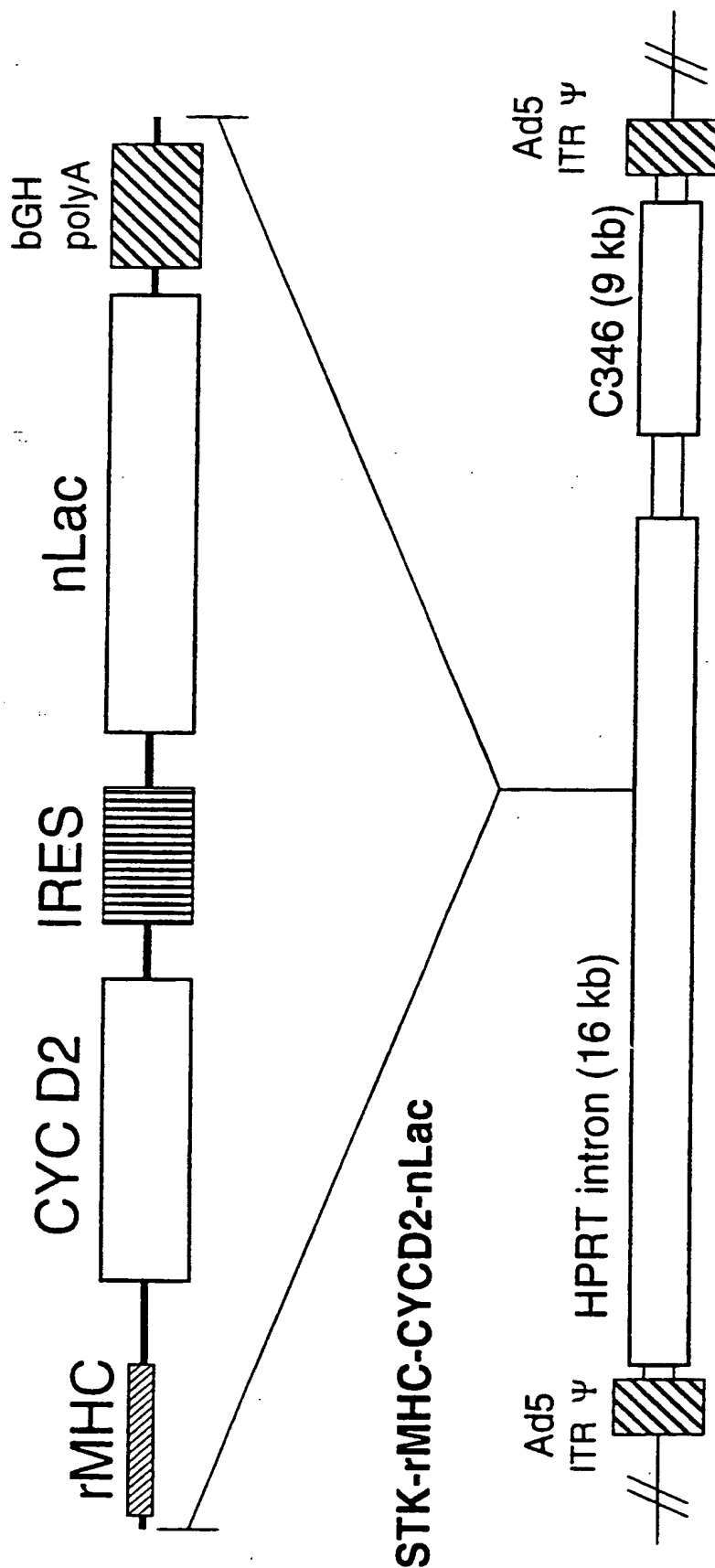


FIGURE 8

STK= third generation adenoviral vector
 Ad5 ITR Ψ= Adenovirus type5 internal repeat
 HPRT intron, C346= human stuffer region
 rMHC= rat myosin heavy chain promoter
 Switch= Gene Switch (gal4 DBD, PR-LBD, p65 activation domain)
 bGH polyA= bovine growth hormone poly adenylation signal
 4xUAS TATA= TATA promoter linked to 4 GAL binding sequences
 Cyclin D2
 SV40 polyA= SV40 poly adenylation signal



STK= third generation adenoviral vector

Ad5 ITR Ψ= Adenovirus type5 internal repeat

HPRT intron, C346= human stuffer region

rMHC= rat myosin heavy chain promoter

IRES= internal ribosomal entry site

bGH polyA= bovine growth hormone poly adenylation signal

4xUAS TATA= TATA promoter linked to 4 GAL binding sequences

CYCD2=Cyclin D2

FIGURE 9

SEQUENCE LISTING

<110> Field, Loren J.
Pasumarthi, Kishore Babu S.

<120> CARDIOMYOCYTES WITH ENHANCED PROLIFERATIVE POTENTIAL,
AND METHODS FOR PREPARING AND USING SAME

<130> 7037-370

<140>

<141>

<160> 8

<170> PatentIn Ver. 2.0

<210> 1

<211> 876

<212> DNA

<213> Mus musculus

<220>

<221> CDS

<222> (4)..(870)

<400> 1

| | |
|---|-----|
| gct atg gag ctg ctg tgc tgc gag gtg gac ccg gtc cgc agg gcc gtg | 48 |
| Met Glu Leu Leu Cys Cys Glu Val Asp Pro Val Arg Arg Ala Val | |
| 1 5 10 15 | |
| ccg gac cgc aac ctg ctg gaa gac cgc gtt ctg cag aac ctg ttg acc | 96 |
| Pro Asp Arg Asn Leu Leu Glu Asp Arg Val Leu Gln Asn Leu Leu Thr | |
| 20 25 30 | |
| atc gag gag cgc tac ctc ccg cag tgt tcc tat ttc aag tgc gtg cag | 144 |

| | | | | | | | | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|
| Ile | Glu | Glu | Arg | Tyr | Leu | Pro | Gln | Cys | Ser | Tyr | Phe | Lys | Cys | Val | Gln | | |
| | | | 35 | | | | | 40 | | | | | 45 | | | | |
| aag | gac | atc | caa | ccg | tac | atg | cgc | agg | atg | gtg | gcc | acc | tgg | atg | cta | 192 | |
| Lys | Asp | Ile | Gln | Pro | Tyr | Met | Arg | Arg | Met | Val | Ala | Thr | Trp | Met | Leu | | |
| | | 50 | | | | | 55 | | | | | 60 | | | | | |
| gag | gtc | tgt | gag | gaa | caa | aag | tgt | gaa | gaa | gag | gtc | ttt | cct | ctg | gcc | 240 | |
| Glu | Val | Cys | Glu | Glu | Gln | Lys | Cys | Glu | Glu | Glu | Val | Phe | Pro | Leu | Ala | | |
| | 65 | | | | | 70 | | | | | 75 | | | | | | |
| atg | aat | tac | ctg | gac | cgt | ttc | ttg | gct | gga | gtc | ccg | act | cct | aag | acc | 288 | |
| Met | Asn | Tyr | Leu | Asp | Arg | Phe | Leu | Ala | Gly | Val | Pro | Thr | Pro | Lys | Thr | | |
| 80 | | | | | 85 | | | | 90 | | | | | 95 | | | |
| cat | ctt | cag | ctc | ctg | ggt | gca | gtg | tgc | atg | ttc | cta | gct | tcc | aag | ctg | 336 | |
| His | Leu | Gln | Leu | Leu | Gly | Ala | Val | Cys | Met | Phe | Leu | Ala | Ser | Lys | Leu | | |
| | | | 100 | | | | | 105 | | | | | | 110 | | | |
| aaa | gag | acc | atc | ccg | ctg | act | gcg | gaa | aag | ctg | tgc | att | tac | acc | gac | 384 | |
| Lys | Glu | Thr | Ile | Pro | Leu | Thr | Ala | Glu | Lys | Leu | Cys | Ile | Tyr | Thr | Asp | | |
| | | | 115 | | | | 120 | | | | | | 125 | | | | |
| aac | tct | gtg | aag | ccc | cag | gag | ctg | ctg | gag | tgg | gaa | ctg | gta | gtg | ttg | 432 | |
| Asn | Ser | Val | Lys | Pro | Gln | Glu | Leu | Leu | Glu | Trp | Glu | Leu | Val | Val | Leu | | |
| | | 130 | | | | | 135 | | | | | 140 | | | | | |
| ggt | aag | ctg | aag | tgg | aac | ctg | gcc | gca | gtc | acc | cct | cac | gac | ttc | att | 480 | |
| Gly | Lys | Leu | Lys | Trp | Asn | Leu | Ala | Ala | Val | Thr | Pro | His | Asp | Phe | Ile | | |
| | 145 | | | | | 150 | | | | | 155 | | | | | | |
| gag | cac | atc | ctt | cgc | aag | ctg | ccc | cag | caa | aag | gag | aag | ctg | tcc | ctg | 528 | |
| Glu | His | Ile | Leu | Arg | Lys | Leu | Pro | Gln | Gln | Lys | Glu | Lys | Leu | Ser | Leu | | |
| 160 | | | | | 165 | | | | | 170 | | | | 175 | | | |
| atc | cgc | aag | cat | gcg | cag | acc | ttc | atc | gct | ctg | tgc | gct | acc | gac | ttc | 576 | |
| Ile | Arg | Lys | His | Ala | Gln | Thr | Phe | Ile | Ala | Leu | Cys | Ala | Thr | Asp | Phe | | |
| | | | 180 | | | | | 185 | | | | | | 190 | | | |
| aag | ttt | gcc | atg | tac | ccg | cca | tcg | atg | att | gca | act | gga | agc | gtg | gga | 624 | |
| Lys | Phe | Ala | Met | Tyr | Pro | Pro | Ser | Met | Ile | Ala | Thr | Gly | Ser | Val | Gly | | |
| | | | 195 | | | | | 200 | | | | | 205 | | | | |
| gca | gcc | atc | tgt | ggg | ctt | cag | cag | gat | gat | gaa | gtg | aac | aca | ctc | acg | 672 | |
| Ala | Ala | Ile | Cys | Gly | Leu | Gln | Gln | Asp | Asp | Glu | Val | Asn | Thr | Leu | Thr | | |
| | | 210 | | | | | 215 | | | | | 220 | | | | | |
| tgt | gat | gcc | ctg | act | gag | ctg | ctg | gcc | aag | atc | acc | cac | act | gat | gtg | 720 | |

Cys Asp Ala Leu Thr Glu Leu Leu Ala Lys Ile Thr His Thr Asp Val
 225 230 235
 gat tgt ctc aaa gcc tgc cag gag caa atc gaa gct ctg ctg ctg aac 768
 Asp Cys Leu Lys Ala Cys Gln Glu Gln Ile Glu Ala Leu Leu Leu Asn
 240 245 250 255
 agc ctg cag cag ttc cgt caa gag cag cat aac gcc gga tcc aag tct 816
 Ser Leu Gln Gln Phe Arg Gln Glu Gln His Asn Ala Gly Ser Lys Ser
 260 265 270
 gtg gaa gat ccg gac caa gcc acc acc cct aca gac gtg cgg gat gtt 864
 Val Glu Asp Pro Asp Gln Ala Thr Thr Pro Thr Asp Val Arg Asp Val
 275 280 285
 gac ctg tgagga 876
 Asp Leu

<210> 2
 <211> 289
 <212> PRT
 <213> Mus musculus

<400> 2
 Met Glu Leu Leu Cys Cys Glu Val Asp Pro Val Arg Arg Ala Val Pro
 1 5 10 15
 Asp Arg Asn Leu Leu Glu Asp Arg Val Leu Gln Asn Leu Leu Thr Ile
 20 25 30
 Glu Glu Arg Tyr Leu Pro Gln Cys Ser Tyr Phe Lys Cys Val Gln Lys
 35 40 45
 Asp Ile Gln Pro Tyr Met Arg Arg Met Val Ala Thr Trp Met Leu Glu
 50 55 60
 Val Cys Glu Glu Gln Lys Cys Glu Glu Glu Val Phe Pro Leu Ala Met
 65 70 75 80
 Asn Tyr Leu Asp Arg Phe Leu Ala Gly Val Pro Thr Pro Lys Thr His
 85 90 95
 Leu Gln Leu Leu Gly Ala Val Cys Met Phe Leu Ala Ser Lys Leu Lys
 100 105 110
 Glu Thr Ile Pro Leu Thr Ala Glu Lys Leu Cys Ile Tyr Thr Asp Asn
 115 120 125

Ser Val Lys Pro Gln Glu Leu Leu Glu Trp Glu Leu Val Val Leu Gly
 130 135 140

Lys Leu Lys Trp Asn Leu Ala Ala Val Thr Pro His Asp Phe Ile Glu
 145 150 155 160

His Ile Leu Arg Lys Leu Pro Gln Gln Lys Glu Lys Leu Ser Leu Ile
 165 170 175

Arg Lys His Ala Gln Thr Phe Ile Ala Leu Cys Ala Thr Asp Phe Lys
 180 185 190

Phe Ala Met Tyr Pro Pro Ser Met Ile Ala Thr Gly Ser Val Gly Ala
 195 200 205

Ala Ile Cys Gly Leu Gln Gln Asp Asp Glu Val Asn Thr Leu Thr Cys
 210 215 220

Asp Ala Leu Thr Glu Leu Leu Ala Lys Ile Thr His Thr Asp Val Asp
 225 230 235 240

Cys Leu Lys Ala Cys Gln Glu Gln Ile Glu Ala Leu Leu Leu Asn Ser
 245 250 255

Leu Gln Gln Phe Arg Gln Glu Gln His Asn Ala Gly Ser Lys Ser Val
 260 265 270

Glu Asp Pro Asp Gln Ala Thr Thr Pro Thr Asp Val Arg Asp Val Asp
 275 280 285

Leu

<210> 3

<211> 873

<212> DNA

<213> Homo sapiens

<220>

<221> CDS

<222> (4)..(870)

<400> 3

gct atg gag ctg ctg tgc cac gag gtg gac ccg gtc cgc agg gcc gtg 48
 Met Glu Leu Leu Cys His Glu Val Asp Pro Val Arg Arg Ala Val
 1 5 10 15

| | |
|---|-----|
| cgg gac cgc aac ctg ctc cga gac gac cgc gtc ctg cag aac ctg ctc | 96 |
| Arg Asp Arg Asn Leu Leu Arg Asp Asp Arg Val Leu Gln Asn Leu Leu | |
| 20 25 30 | |
| acc atc gag gag cgc tac ctt ccg cag tgc tcc tac ttc aag tgc gtg | 144 |
| Thr Ile Glu Glu Arg Tyr Leu Pro Gln Cys Ser Tyr Phe Lys Cys Val | |
| 35 40 45 | |
| cag aag gac atc caa ccc tac atg cgc aga atg gtg gcc acc tgg atg | 192 |
| Gln Lys Asp Ile Gln Pro Tyr Met Arg Arg Met Val Ala Thr Trp Met | |
| 50 55 60 | |
| ctg gag gtc tgt gag gaa cag aag tgc gaa gaa gag gtc ttc cct ctg | 240 |
| Leu Glu Val Cys Glu Glu Gln Lys Cys Glu Glu Glu Val Phe Pro Leu | |
| 65 70 75 | |
| gcc atg aat tac ctg gac cgt ttc ttg gct ggg gtc ccg act ccg aag | 288 |
| Ala Met Asn Tyr Leu Asp Arg Phe Leu Ala Gly Val Pro Thr Pro Lys | |
| 80 85 90 95 | |
| tcc cat ctg caa ctc ctg ggt gct gtc tgc atg ttc ctg gcc tcc aaa | 336 |
| Ser His Leu Gln Leu Leu Gly Ala Val Cys Met Phe Leu Ala Ser Lys | |
| 100 105 110 | |
| ctc aaa gag acc agc ccg ctg acc gcg gag aag ctg tgc att tac acc | 384 |
| Leu Lys Glu Thr Ser Pro Leu Thr Ala Glu Lys Leu Cys Ile Tyr Thr | |
| 115 120 125 | |
| gac aac tcc atc aag cct cag gag ctg ctg gag tgg gaa ctg gtg gtg | 432 |
| Asp Asn Ser Ile Lys Pro Gln Glu Leu Leu Glu Trp Glu Leu Val Val | |
| 130 135 140 | |
| ctg ggg aag ttg aag tgg aac ctg gca gct gtc act cct cat gac ttc | 480 |
| Leu Gly Lys Leu Lys Trp Asn Leu Ala Ala Val Thr Pro His Asp Phe | |
| 145 150 155 | |
| att gag cac atc ttg cgc aag ctg ccc cag cag cgg gag aag ctg tct | 528 |
| Ile Glu His Ile Leu Arg Lys Leu Pro Gln Gln Arg Glu Lys Leu Ser | |
| 160 165 170 175 | |
| ctg atc cgc aag cat gct cag acc ttc att gct ctg tgt gcc acc gac | 576 |
| Leu Ile Arg Lys His Ala Gln Thr Phe Ile Ala Leu Cys Ala Thr Asp | |
| 180 185 190 | |
| ttt aag ttt gcc atg tac cca ccg tcg atg atc gca act gga agt gtg | 624 |
| Phe Lys Phe Ala Met Tyr Pro Pro Ser Met Ile Ala Thr Gly Ser Val | |
| 195 200 205 | |

gga gca gcc atc tgt ggg ctc cag cag gat gag gaa gtg agc tcg ctc 672
 Gly Ala Ala Ile Cys Gly Leu Gln Gln Asp Glu Glu Val Ser Ser Leu
 210 215 220

act tgt gat gcc ctg act gag ctg ctg gct aag atc acc aac aca gac 720
 Thr Cys Asp Ala Leu Thr Glu Leu Leu Ala Lys Ile Thr Asn Thr Asp
 225 230 235

gtg gat tgt ctc aaa gct tgc cag gag cag att gag gcg gtg ctc ctc 768
 Val Asp Cys Leu Lys Ala Cys Gln Glu Gln Ile Glu Ala Val Leu Leu
 240 245 250 255

aat agc ctg cag cag tac cgt cag gac caa cgt gac gga tcc aag tcg 816
 Asn Ser Leu Gln Gln Tyr Arg Gln Asp Gln Arg Asp Gly Ser Lys Ser
 260 265 270

gag gat gaa ctg gac caa gcc agc acc cct aca gac gtg cgg gat atc 864
 Glu Asp Glu Leu Asp Gln Ala Ser Thr Pro Thr Asp Val Arg Asp Ile
 275 280 285

gac ctg tga 873
 Asp Leu

<210> 4

<211> 289

<212> PRT

<213> Homo sapiens

<400> 4

Met Glu Leu Leu Cys His Glu Val Asp Pro Val Arg Arg Ala Val Arg
 1 5 10 15

Asp Arg Asn Leu Leu Arg Asp Asp Arg Val Leu Gln Asn Leu Leu Thr
 20 25 30

Ile Glu Glu Arg Tyr Leu Pro Gln Cys Ser Tyr Phe Lys Cys Val Gln
 35 40 45

Lys Asp Ile Gln Pro Tyr Met Arg Arg Met Val Ala Thr Trp Met Leu
 50 55 60

Glu Val Cys Glu Glu Gln Lys Cys Glu Glu Glu Val Phe Pro Leu Ala
 65 70 75 80

Met Asn Tyr Leu Asp Arg Phe Leu Ala Gly Val Pro Thr Pro Lys Ser
 85 90 95

His Leu Gln Leu Leu Gly Ala Val Cys Met Phe Leu Ala Ser Lys Leu
 100 105 110

Lys Glu Thr Ser Pro Leu Thr Ala Glu Lys Leu Cys Ile Tyr Thr Asp
 115 120 125

Asn Ser Ile Lys Pro Gln Glu Leu Leu Glu Trp Glu Leu Val Val Leu
 130 135 140

Gly Lys Leu Lys Trp Asn Leu Ala Ala Val Thr Pro His Asp Phe Ile
 145 150 155 160

Glu His Ile Leu Arg Lys Leu Pro Gln Gln Arg Glu Lys Leu Ser Leu
 165 170 175

Ile Arg Lys His Ala Gln Thr Phe Ile Ala Leu Cys Ala Thr Asp Phe
 180 185 190

Lys Phe Ala Met Tyr Pro Pro Ser Met Ile Ala Thr Gly Ser Val Gly
 195 200 205

Ala Ala Ile Cys Gly Leu Gln Gln Asp Glu Glu Val Ser Ser Leu Thr
 210 215 220

Cys Asp Ala Leu Thr Glu Leu Leu Ala Lys Ile Thr Asn Thr Asp Val
 225 230 235 240

Asp Cys Leu Lys Ala Cys Gln Glu Gln Ile Glu Ala Val Leu Leu Asn
 245 250 255

Ser Leu Gln Gln Tyr Arg Gln Asp Gln Arg Asp Gly Ser Lys Ser Glu
 260 265 270

Asp Glu Leu Asp Gln Ala Ser Thr Pro Thr Asp Val Arg Asp Ile Asp
 275 280 285

Leu

<210> 5

<211> 5443

<212> DNA

<400> 5

ggatcctgca aggtcacaca agggctctcca cccaccaggt gccctagtct caatttcagt 60

-8-

ttccatgcct tgttctcaca atgctggcct cccagagct aatttggact ttgtttttat 120
ttcaaaaggg cctgaatgag gagtagatct tgtgctaccc agctctaagg gtgcccgtga 180
agccctcaga cctggagcct ttgcaacagc cctttaggtg gaagcagaat aaagcaattt 240
tccttaaagc caaaatcctg cctctagact cttcttctct gacctcggtc cctgggctct 300
aggggtgggga ggtggggcctt ggaagaagaa ggtggggaag tggcaaaagc cgatccctag 360
ggccctgtga agttcggagc cttccctgta cagcactggc tcatagatcc tcctccagcc 420
aaacatagca agaagtgata cctcctttgt gacttcccca ggcccagtac ctgtcagggt 480
gaaacaggat ttagagaagc ctctgaactc acctgaactc tgaagctcat ccaccaagca 540
agcacctagg tgccactgct agttagtatc ctacgctgat aatatgcaga gctggggccac 600
agaagtccctg ggggtgtagga actgaccagt gacttttcag tcggcaaagg tatgaccccc 660
tcagcagatg tagtaatgtc cccttagatc ccatcccagg caggtctcta agaggacatg 720
ggatgagaga tgtagtcatg tggcattcca aacacagcta tccacagtgt cccttgcccc 780
ttccacttag ccaggaggac agtaacctta gcctatcttt cttcctcccc atcctcccag 840
gacacacccc ctgggtctgca gtattcattt cttccttcac gtcccctctg tgacttccat 900
ttgcaaggct tttgacctct gcagctgctg gaagatagag tttggcccta ggtgtggcaa 960
gccatctcaa gagaaagcag acaacagggg gaccagattt tggaaggatc aggaactaaa 1020
tcactggcgg gcctgggggt agaaaaaaga gtgagtgagt ccgctccagc taagccaagc 1080
tagtccccga gatactctgc cacagctggg ctgctcgggg tagctttagg aatgtgggtc 1140
tgaaagacaa tgggattgga agacatctct ttgagtctcc cctcaacccc acctacagac 1200
acactcgtgt gtggccagac tcctgttcaa cagccctctg tgttctgacc actgagctag 1260
gcaaccagag catgggccct gtgctgagga tgaagagttg gttaccaata gcaaaaacag 1320
caggggaggg agaacagaga acgaaataag gaaggaagaa ggaaaggcca gtcaatcaga 1380
tgcagtcaga agagatggga agccaacaca cagcttgagc agaggaaaca gaaaaggag 1440
agattctggg cataaggagg ccacagaaag aagagcccag gcccccaag tctcctcttt 1500

-9-

ataccctcat cccgtctccc aattaagccc actcttcttc ctagatcaga cctgagctgc 1560
agcgaagaga cccgtaggga ggatcacact ggatgaagga gatgtgtgga gaagtccagg 1620
gcaacctaag agccagagcc taaaagagca agagataaag gtgcttcaaa ggtggccagg 1680
ctgtgcacac agaggggtcga ggactggtgg tagagcctca agataaggat gatgctcaga 1740
atgggcgggg ggggggattc tggggggggg agagagaagg tgagaaggag cctggaacag 1800
agaatctgga agcgctggaa acgataccat aaagggaaga acccaggcta ccttttagatg 1860
taaatacatga aagacaggga gaagggaagc tggagagagt agaaggacct cggggcaaga 1920
catggaagca aggacaagcc aggttgagcg ctccgtgaaa tcagcctgct gaaggcagag 1980
ccctggtatg agcaccagaa cagcagaggc tagggttaat gtcgagacag ggaacagaag 2040
gtagacacag gaacagacag agacggggga gccaggtaac aaaggaatgg tccttctcac 2100
ctgtggccag agcgtccatc tgtgtccaca tactctagaa tgttcatcag actgcagggc 2160
tggcttgga ggcagctgga aagagtatgt gagagccagg ggagacaagg gggcctagga 2220
aaggaagaag agggcaaacc aggccacaca agagggcaga gcccagaact gagttaactc 2280
cttccttggt gcattctcca taggaggcag tgggaactct gtgaccacca tccccatga 2340
gccccacta cccataccaa gtttggcctg agtggcattc taggttcctt gaggacagag 2400
cctggccttt gtctcttgga cctgacccaa gctgacccaa tgttctcagt accttatcat 2460
gccctcaaga gcttgagaac caggcagtga catattaggc catgggctaa ccctggagct 2520
tgcacacagg agcctcaagt gacctccagg gacacagctg cagacagggtg gcctttatcc 2580
ccaaagagca accatttggc ataggtggct gcaaattggga atgcaagggt gaatcagggtc 2640
ccttcaagaa tactgcatgc aagacctaag acccctggag agaggggtat gtcctgccc 2700
ccaccacca taaggggagt gaactatcct agggggctgg cgaccttggg gagacaccac 2760
attactgaga gtgctgagcc cagaaaaact gaccgccctg tgtcctgccc acctccacac 2820
tctagagcta tattgagagg tgacagtaga taggggtggga gctggtagca gggagagtgt 2880
tcctgggtgt gaggggtgtag gggaaagcca gagcagggga gtctggcttt gtctcctgaa 2940

SUBSTITUTE SHEET (RULE 26)

-10-

cacaatgtct acttagttat aacagggcatg acctgctaaa gacccaacat ctacgacctc 3000
tgaaaagaca gcagccctgg aggacagggg ttgtctctga gccttggggtg cttgatgggtg 3060
ccacaaagga gggcatgagt gtgagtataa ggccccagga gcgttagaga agggcacttg 3120
ggaaggggtc agtctgcaga gcccctatcc atggaatctg gagcctgggg ccaactgggtg 3180
taaattctctg ggcttgccag gcattcaaag cagcacctgc atcctctggc agcctgggga 3240
ggcggaaggg agcaaccccc cacttatacc ctttctccct cagccccagg attaacacct 3300
ctggccttcc cccttccac ctcccatcag gagtggaggg ttgcagaggg agggtaaaaa 3360
cctacatgtc caaacatcat ggtgcacgat atatggatca gtatgtgtag aggcaagaaa 3420
ggaaatctgc aggcttaact gggttaatgt gtaaagtctg tgtgcatgtg tgtgtgtctg 3480
actgaaaacg ggcattggctg tgcagctgtt cagttctgtg cgtgagggtta ccagactgca 3540
ggtttgtgtg taaattgccc aaggcaaagt ggggtgaatcc cttccatggt ttaaagagat 3600
tggtatgatgg cctgcatctc aaggaccatg gaaaatagaa tggacactct atatgtgtct 3660
ctaagctaag gtagcaaggt ctttgaggga cacctgtcta gagatgtggg caacagagac 3720
tacagacagt atctgtacag agtaaggaga gagaggaggg ggtgtagaat tctcttacta 3780
tcaaagggaa actgagtcgt gcacctgcaa agtggatgct ctccctagac atcatgactt 3840
tgtctctggg gagccagcac tgtggaactt caggtctgag agagtaggag gctccccctca 3900
gcctgaagct atgcagatag ccagggttga aagggggaag ggagagcctg ggatgggagc 3960
ttgtgtgttg gaggcagggg acagatatta agcctggaag agaagggtgac cttaccag 4020
ttgttcaact cacccttcag attaaaaata actgaggtaa gggcctgggt aggggaggtg 4080
gtgtgagacg ctctgtctc tcctctatct gccatcggc cctttgggga ggaggaatgt 4140
gccaaggac taaaaaagg ccatggagcc agaggggcga gggcaacaga ctttcatgg 4200
gcaaaccttg gggccctgct gtcctctgt cacctccaga gccaagggat caaaggagga 4260
ggagccagga caggagggaa gtgggagggg gggcccagc agaggactcc aaatttaggc 4320
agcaggcata tgggatggga tataaagggg ctggagcact gagagctgtc agagatttct 4380

SUBSTITUTE SHEET (RULE 26)

-11-

ccaacccagg taagagggag ttctgggtgg gggctcttca cccacaccag acctctcccc 4440
 acctagaagg aaactgcctt tcctggaagt ggggttcagg ccggtcagag atctgacagg 4500
 gtggccttcc accagcctgg gaagtcttca gtggcaggag gtttccacaa gaaacactgg 4560
 atgccccctc ccttacgctg tcttctccat ctctctctg gggatgctcc tccccgtctt 4620
 ggtttatctt ggctcttcgt ctctagcaag atttgccctg tgctgtccac tccatctttc 4680
 tctactgtct ccgtgccttg ccttgccttc ttgcgtgtcc ttcctttcca cccatttctc 4740
 acttcacctt ttctccccct ctcatttgta ttcctccttc ctctcttctt tccttccttc 4800
 ctctcttctt tccttccttc cttctctctt tccttccttc ctctcttctt tccttccttc 4860
 ctctcttctt gtgtcagagt gctgagaatc acacctgggg ttcccaccct tatgtaaaca 4920
 atcttccagt gagccacagc ttcagtgtct ctgggtgtct tcttaccttc ctacccccct 4980
 ggcttgtcct gttccatcct ggtcaggatc tctagattgg tctcccagcc tctgtacttc 5040
 ctcttctctg ctgttctctt ctctgtccag ctgcgccact gtggtgcctc gttccagctg 5100
 tgggtccacat tcttcaggat tctctgaaaa gttaaccagg tgagaatgtt tccccgttag 5160
 acagcagatc acgattctcc cggaagtcag gcttccagcc ctctctttct ctgcccagct 5220
 gcccggcact cttagcaaac ctccaggcacc ctacccccac atagacctct gacagagaag 5280
 caggcacttt acatggagtc ctgggtgggag agccataggg tacgggtgtaa aagaggcagg 5340
 gaagtgggtg tgtaggaaaag tcaggacttc acatagaagc ctagcccaca ccagaaatga 5400
 cagacagatc cctcctatct cccccataag agtttgagtc gac 5443

<210> 6

<211> 134

<212> DNA

<400> 6

gtggatgggc agcctatgat tggaatgtcc tctcaagtag aggaggtag ggtttatgag 60
 gacacagagg agcttctctg ggatccagac atgataagat acattgatga gtttggacaa 120
 accacaacta gaat 134

-12-

<210> 7
<211> 30
<212> DNA

<400> 7
gctatggagc tgctgtgctg cgaggtggac

30

<210> 8
<211> 30
<212> DNA

<400> 8
tcctcacagg tcaacatccc gcacgtctgt

30

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
28 December 2000 (28.12.2000)

PCT

(10) International Publication Number
WO 00/78119 A3

(51) International Patent Classification⁷: C12N 1/00,
15/63, 15/85, C07H 21/04

(21) International Application Number: PCT/US00/16827

(22) International Filing Date: 19 June 2000 (19.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/139,942 18 June 1999 (18.06.1999) US

(71) Applicant (for all designated States except US): **ADVANCED RESEARCH & TECHNOLOGY INSTITUTE, INC.** [US/US]; Suite 100, 1100 Waterway Boulevard, Indianapolis, IN 46202 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **FIELD, Loren, J.** [US/US]; 741 West 72nd, Indianapolis, IN 46260 (US). **PASUMARTHI, Kishore, Babu, S.** [IN/US]; Apartment 208, 1152 North White River Parkway West Drive, Indianapolis, IN 46222 (US).

(74) Agents: **GANDY, Kenneth, A.** et al.; Woodard, Emhardt, Naughton, Moriarty & McNett, Bank One Center/Tower, Suite 3700, 111 Monument Circle, Indianapolis, IN 46204 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

(88) Date of publication of the international search report:
7 September 2001

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.



WO 00/78119 A3

(54) Title: CARDIOMYOCYTES WITH ENHANCED PROLIFERATIVE POTENTIAL

(57) Abstract: Described are methods *in vitro* and *in vivo* which involve the use of increased cyclin D2 activity to activate the cell cycle of cardiomyocytes as a baseline measure and/or in response to stimuli. Also described are vectors useful for these purposes, and cardiomyocyte cells exhibiting an activated cell cycle. Transgenic cyclin D2 animal models are also described.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/16827

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : C12N 1/00, 15/63, 15/85; C07H 21/04
US CL : 435/6, 243, 320.1, 455; 536/23.1, 24.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 435/6, 243, 320.1, 455; 536/23.1, 24.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST, DIALOG

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|--|-----------------------|
| Y | HAUK ET AL. E2F-1 induces cell cycle reentry in cardiomyocytes through release of kip1/cip cdk inhibitors. Circulation. 27 October 1998, Vol. 98 (17 SUPPL.), page p1262. See entire abstract. | 1-9 & 29-39 |
| Y | US 5,688,665 A (MASSGUE et al.) 18 November 1997 (18.11.97), see especially the abstract, columns 2-4, 17 and 24-25. | 1-9 & 29-39 |
| Y | US 5,869,640 A (BEACH) 09 February 1999 (09/02/99), see especially the abstract, and columns 3 and 7. | 1-9 & 29-39 |
| Y | HOLYOAKE et al. The normal cell cycle activation program is exploited during the infection of quiescent B lymphocytes by Epstein-Barr virus. Cancer Research 01 November 1995, Vol. 55, pages 4784-4787, see the entire article. | 1-9 & 29-39 |
| Y | TAMAMORI et al. Essential roles for G1 cyclin-dependent kinase activity in development of cardiomyocyte hypertrophy. American Journal of Physiology. December 1998, Vol. 275 (6Pt.2), pages H2036-H2040, see especially the abstract and introduction. | 1-9 & 29-39 |
| Y | US 5,821,234 A (DZAU) 13 October 1998 (13.10.98) see especially the abstract and columns 1-4. | 1-9 & 29-39 |



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search

15 December 2000 (15.12.2000)

Date of mailing of the international search report

APR 05 2001

Name and mailing address of the ISA/US

Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

William Sandals
William Sandals

Telephone No. (703) 308-1235

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/16827

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: 1-9 & 29-39

Remark on Protest

☐
☐

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

THIS PAGE BLANK (USPTO)

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☐ FADED TEXT OR DRAWING
- ☒ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.

THIS PAGE BLANK (USPTO)